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DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

AN INVESTIGATION
OF
EXPLOSION-PROOF MOTORS

BY

H. H. CLARK

WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

First edition. August, 1912.

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AN INVESTIGATION OF EXPLOSION-PROOF MOTORS.

By H. H. Clark.

INTRODUCTION.

DEFINITION OF TERM "EXPLOSION-PROOF."

The term "explosion-proof," as applied by the Bureau of Mines to an electric motor, refers to a motor inclosed by a casing so constructed that an explosion of a mixture of mine gas (methane) and air within the casing will not ignite a mixture of the same gas surrounding the motor. There are two classes of motors so constructed: First, a totally inclosed class built strong enough to withstand high internal pressures and so designed that the efficiency of all inclosing covers can be satisfactorily maintained; second, a class provided with relief openings or valves designed to relieve the pressure of an explosion within the motor casing and to cool any products of combustion discharged through the valves.

A satisfactory motor of the first class is much more expensive to build than an equally safe motor of the second class. For this reason, attempts to make motors explosion-proof have been confined chiefly to motors of the second class.

THEORY OF EXPLOSION-PROOF PROTECTION.

The function of explosion-proof devices for electric motors is to reduce below the ignition point of gas (methane) the temperature of any flames that may be discharged from the motor casing. The temperature reduction is effected by removing the requisite amount of heat from the flames during their passage through the devices. Various plans have been proposed and developed for thus removing heat from the products of explosion. The principle of the Davy safety lamp has been the basis of most of the protective devices designed for explosion-proof motors. The application of this principle consists in causing the discharged gases to pass over or through metallic plates or screens which by conduction remove the heat from the gases. In some types of devices the cooling effect of expansion is also utilized.

For the sake of simplicity, in this report the means used to cool incandescent gases are termed "protective devices" whether they consist of valves, layers of gauze, or metal plates.

PROCEDURE OF INVESTIGATION.

The investigation described in this bulletin was undertaken by the Bureau of Mines as one of several investigations having for their purpose the ascertaining of methods for lessening the risks attending the use of electricity in mining.

The bureau began this investigation by sending a circular letter to manufacturers of electric motors for mine service, stating that the bureau proposed to make tests of electric motors designed for operation in the presence of gas (methane) in order to determine their suitability for such service. This letter was sent to all manufacturers whom the bureau believed would be interested in the proposed tests. Five motors were submitted for test, no two being protected in exactly the same manner.

In this report the results of tests are related to the various types of protection employed which are described in detail.

DETERMINATION OF TEST CONDITIONS.

According to the definition of an explosion-proof motor, such a machine can presumably be safely operated in an atmosphere containing gas (methane) under conditions most conducive to explosion, provided that the protective devices with which the motor is equipped are in good condition and in their proper places. In conducting the investigation here reported, an effort was made to produce conditions that would probably introduce the greatest elements of danger. In the earlier tests especially, and to some extent in subsequent tests, it was not evident just what the most dangerous conditions would be. The design of some of the protective devices required the introduction of special conditions which are in this report recorded under the description of the tests of such devices. A list of conditions common to all tests follows.

CONDITIONS COMMON TO ALL TESTS.

CONSTANTS.

The constants of the investigation consisted in assuming:

(*a*) That sparking sufficient to ignite gas (see p. 11) was present in the motor casing.

(*b*) That the motor casing was completely filled with an explosive gaseous mixture.

(*c*) That the motor casing was completely surrounded with a similar mixture.

CONTROLLED VARIABLES.

The controlled variables of the investigation were:

(*a*) The ratio of gas to air in the gaseous mixtures.

(*b*) The point within the motor casing at which the mixture was ignited.

(*c*) The presence of coal dust within the motor casing.

UNCONTROLLED VARIABLE.

The variable which was observed but not controlled was:
The temperature of the gaseous mixture surrounding the motor.

TEST ASSUMPTIONS.

The reasons for assuming the constants are obvious and require no explanation nor comment. A discussion of the variables follows.

The ratio of gas (see p. 11) to air within the motor casing was varied from the value that gave maximum pressure and heat in order to determine the effect of slow-burning mixtures which produce a lower but longer sustained pressure.

The location of the point of ignition with reference to the relief openings was varied because that factor has an influence upon the pressures produced by explosions within the casing.

Coal dust was sifted into the housings of the relief openings in order to observe the influence of the dust upon the pressures developed within the motor casing, and also to determine if the presence of dust assists in the communication of heat from the interior of the motor casing to the gaseous mixture surrounding it.

No attempt was made to control the temperature of the motor or to increase it by operation under load lest the severity of the conditions would be lessened. Raising the temperature of the motor would have increased the temperature of the protective devices and decreased their capacity for cooling the products of explosion. At the same time, however, the amount of gaseous mixture which the casing could contain would have been decreased, the latter effect more than counterbalancing the former, as is shown below.

In testing motors for explosion-proof qualities the danger point is reached when the products of explosion are discharged through the protective devices at a temperature higher than 650° C.,[a] the ignition temperature of methane. It is reasonable to assume that, if the temperature of the discharged products of explosion is 650° C., the parts of the protective devices that are in immediate contact with the products of explosion must have attained a temperature of at least 300° C. In considering the conditions that exist when a motor is tested cold, let the initial temperature of both the gas and the protective devices be assumed as 25° C., the absolute initial temperature of the gaseous mixture being 273° plus 25°, or 298° C. The range of temperature through which the protective devices must be raised before they can discharge dangerously hot gases will therefore be at least 300° C. minus 25° C., or 275° C. If the motor be tested under the conditions of its maximum guaranteed temperature rise of 75° C. above 25° C., the average temperature of the gaseous mixture within the motor casing could be hardly less than 75° C. (348° C., absolute), and the temperature of the protective devices could be hardly greater than 60° C. The temperature range of the protective devices would therefore be 300° minus 60°, or 240° C., about 12.7 per cent less than when testing the motor cold. The amount of gaseous mixture that the motor casing can contain at an absolute temperature of 348° C. is $\frac{298}{348}$ of the amount that it can contain at an absolute temperature of 298° C., or about 14.4 per cent less. Thus it is evident that although the temperature rise of the protective devices necessary to produce dangerous conditions would be decreased 12.7 per cent by raising the initial temperature of the motor 75° C., the available heat in the gaseous mixture would, at the same time, be decreased by an even greater percentage.

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[a] Dixon, H. B., and Coward, H. F., The ignition temperature of gases. Chemical News, vol. 99, 1909, p. 139.

For the reasons given above, no attempt was made to raise the temperature of either the motor or the surrounding air when that temperature fell below the probable underground temperature. The pressures obtained in the tests seemed to prove the wisdom of this practice, although they do not correspond exactly in all cases. Of 17 groups of tests, made upon 3 different types of protection under conditions that allowed the effect of temperature to be satisfactorily observed, only 1 group showed a higher pressure for the maximum temperature than for the minimum, and the difference was only one-half pound in that group. In making the comparison only those groups were considered in which the mixture contained 8.6 per cent gas, and in which the tests differed in temperature by 8° C., or more.

Some of the more notable examples of the inverse variation of pressure with temperature are tabulated below. These are all abstracted from the results of tests of the type A[a] devices, the temperature variation being greater during the tests of these devices than with the other types tested.

Variation of pressures with temperatures in explosion-proof motors.

Group No.	Maximum temperatures.	Corresponding pressures.	Minimum temperatures.	Corresponding pressures.
	° C.	*Pounds per square inch.*	*° C.*	*Pounds per square inch.*
1	35	19.0	6	28.0
19	24	38.0	2	43.0
34	30	35.5	3	37.5
35	23	42.0	5	45.5
17	27	20.5	0	27.5
18	18	40.5	0	45.8
31	27	36.0	3	47.0
32	15	40.0	2	47.0

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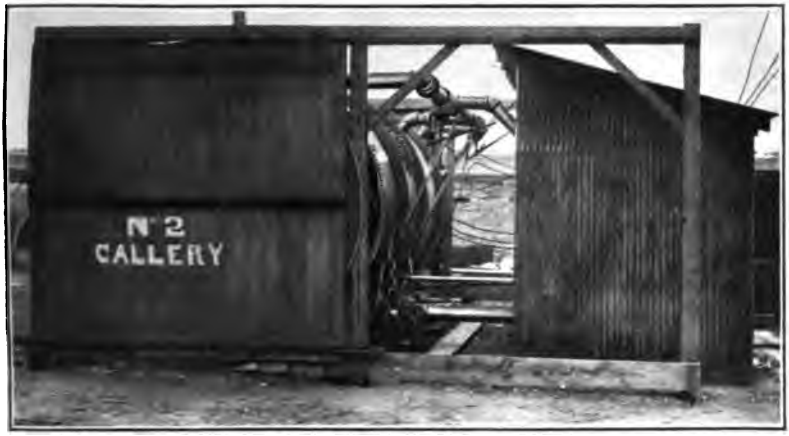
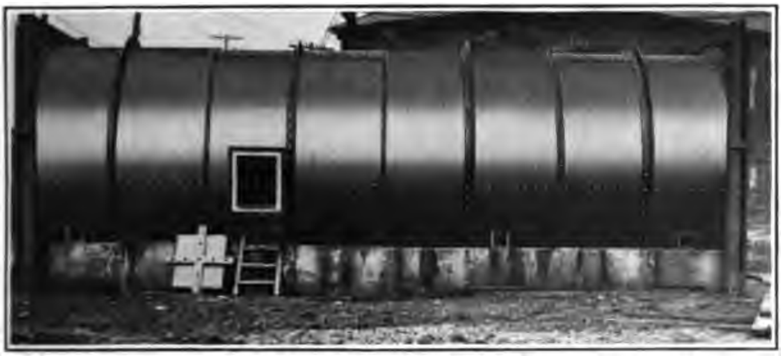
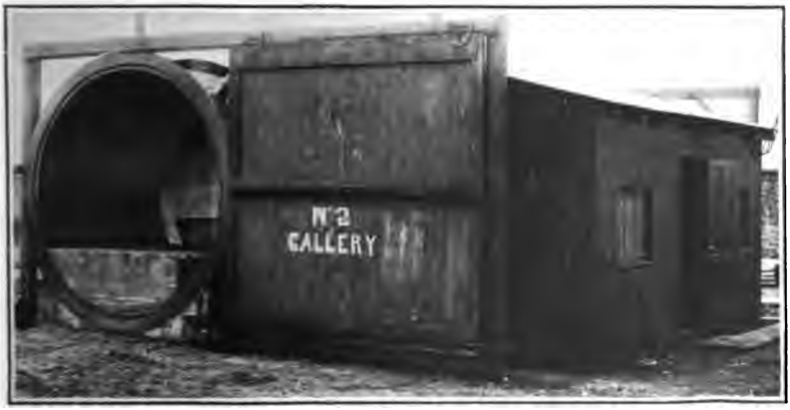
[a] See p. 23.



A. GALLERY, SHOWING TESTING HOUSE AND PIPE CONNECTIONS.



B. SIDE VIEW OF GALLERY, SHOWING MANHOLES.



C. END VIEW OF GALLERY, SHOWING PAPER DIAPHRAGM.

GAS AND EQUIPMENT USED.

GAS.

The natural gas supplied to the city of Pittsburgh was used in all tests. Its composition[a] is approximately 82 per cent methane or marsh gas, 16.4 per cent ethane, 1.5 per cent nitrogen, and a trace of carbon dioxide. The term "gas" wherever used in this report refers to this natural gas.

The most explosive mixture[b] of such gas and air is one combined in the proportion of 8.6 : 91.4. This mixture also burns most rapidly and evolves the greatest amount of heat.

In this report a mixture containing more than 8.6 per cent of gas is termed an "overgassed" mixture, and a mixture containing less than 8.6 per cent of gas is termed an "undergassed" mixture.

TESTING APPARATUS.

The apparatus used in the tests included the following:

(1) A gas-tight gallery or inclosure in which the motor to be tested was installed. (Pl. I.)

(2) A circulating fan for mixing the gas and air within the gallery.

(3) A system of piping connecting the gallery and circulating fan.

(4) A device for determining the percentage of gas in the mixture. (Pl. II and fig. 1.)

(5) A pressure indicator attached to the motor casing to record the pressure developed therein by the explosion.

(6) Spark plugs mounted within the motor casing and operated by an induction coil.

(7) A system of piping and valves connecting the motor casing with the fan intake for the purpose of filling the motor casing with the gaseous mixture.

TESTING GALLERY.

The gallery in which the motor was installed for the tests was a boiler-plate cylinder, 10 feet in diameter and 30 feet in length, set horizontally upon a concrete foundation. Seven feet from each end the cylinder was stopped off with diaphragms of heavy manila paper reinforced with cheese cloth and painted with one coat of white lead and oil to make them gas-tight. A manhole cut in the side of the gallery between the diaphragms made entrance possible without the disturbing of the paper stoppings. Observation windows of heavy plate glass were placed at intervals along the sides of the gallery. Plate I shows the general appearance of the gallery and testing house. Electrical connections were brought through bushings in the side of the gallery to a slate terminal board.

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[a] Burrell, G. A., The natural gas used at Pittsburgh: Bull. 15, Bureau of Mines, 1912, p. 66.

[b] Idem, p. 77.

Pipe connections for the circulating fan were made so that the mixtures entered and left at the same end of the gallery. The discharge point was about in the middle of one end and directed the gases horizontally along the gallery. The velocity with which the mixtures entered carried them the entire length of the gallery and in returning to the point where the fan intake was connected they filled the gallery completely with a uniform mixture.

CIRCULATING FAN AND PIPING.

A 6-inch exhaust fan, driven by an electric motor, was installed outside the gallery for mixing and circulating the gas and air. This fan, as connected, had a capacity of about 1,000 cubic feet per minute. The gas-feed connection was made to the fan intake so as to obtain a preliminary mixing of the gas and air before they entered the gallery.

The fan was so connected to the gallery that it could be used either to circulate the mixture through the gallery, draw the mixture through the motor casing, withdraw the mixture from the gallery, or force fresh air into the gallery.

GAS-PERCENTAGE INDICATOR.

It was necessary to be able to determine quickly and accurately when the gas and air were mixed in proper proportions. Chemical analysis, although accurate, was obviously not suited to the purpose. On account of conditions which were unavoidably associated with the test it was not expedient to attempt to obtain accurate mixtures by combining proportionate volumes of gas and air. To overcome these difficulties, an instrument[a] was devised that burned a small quantity of the gaseous mixture in close proximity to a thermocouple that was connected to a delicate millivoltmeter. Plate II shows the general arrangement of the apparatus; figure 1 shows the details. This device was connected to the fan discharge so as to indicate the percentage of gas in the mixture that was being circulated through the gallery. By setting the valves in the piping system so that the fan took the mixture from the motor casing only, it was possible to determine immediately and accurately when the casing had become filled with the correct mixture.

The operation of the device was simple. The mixture was fed to the device at constant pressure, maintained by reference to a sensitive water gage connected at the point *c*, and was burned at the point *a* just below the thermocouple, ignition being accomplished by a jump spark between the point *b* and the casing of the plug. Once

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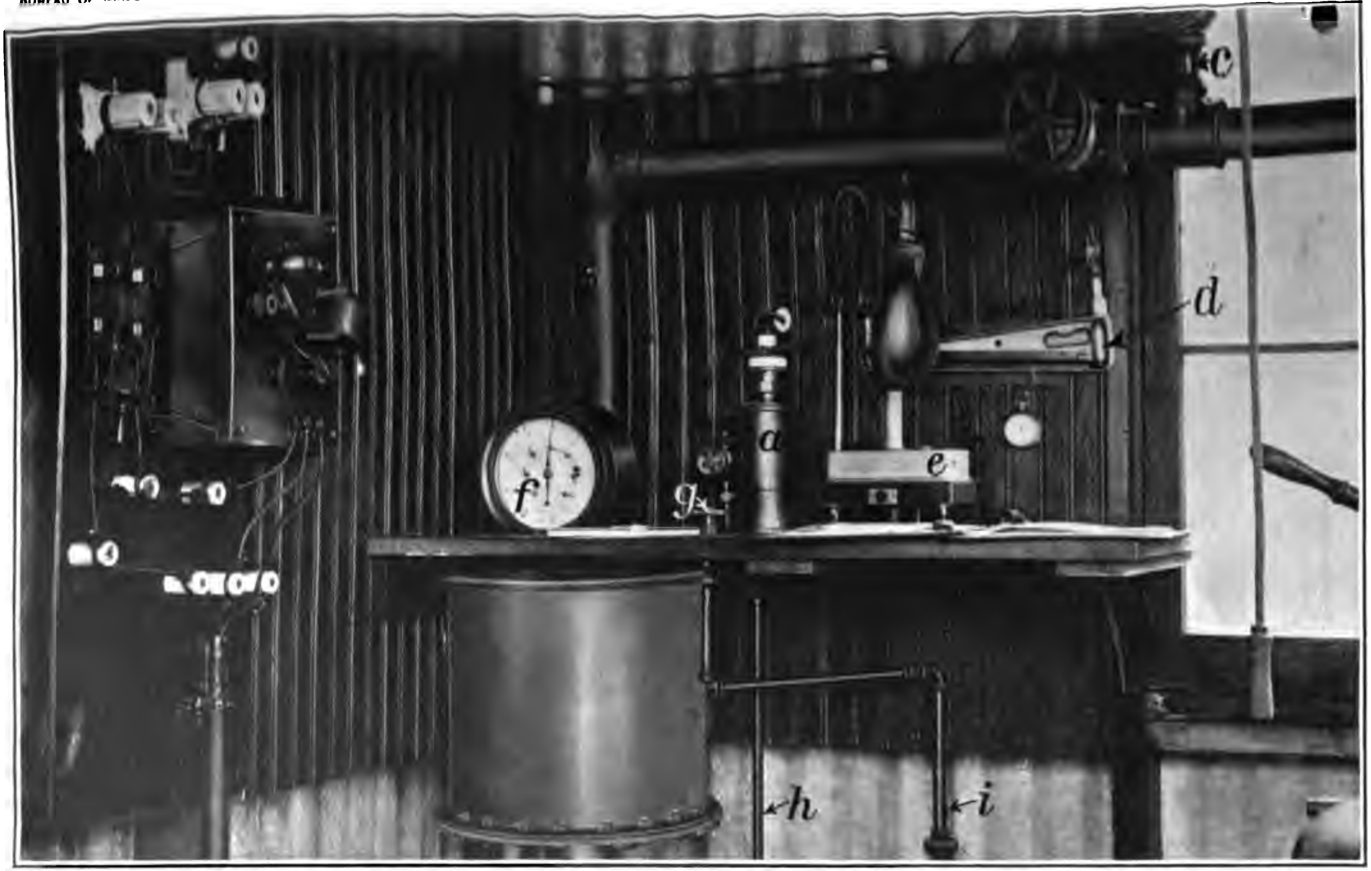
[a] In this instrument use was made of a combined automobile spark plug and thermocouple invented and developed by N. Munroe Hopkins, of Washington, D. C.



ARRANGEMENT OF RECORDING APPARATUS. *a*, GAS-PERCENTAGE INDICATOR; *c*, AIR SUPPLY; *d*, WATER GAGE; *e*, MILLIVOLTMETER; *f*, GAS METER; *g*, INDICATOR-CONTROL VALVE; *h*, WATER-JACKET SUPPLY PIPE; *i*, INDICATOR CONNECTION TO FAN DISCHARGE.

ignited, the gas burned as a continuous flame and not as a series of explosions. Obviously the deflection of the millivoltmeter was maximum when the ratio of gas to air in the mixture was such that the greatest amount of heat was evolved when the mixture was burned.

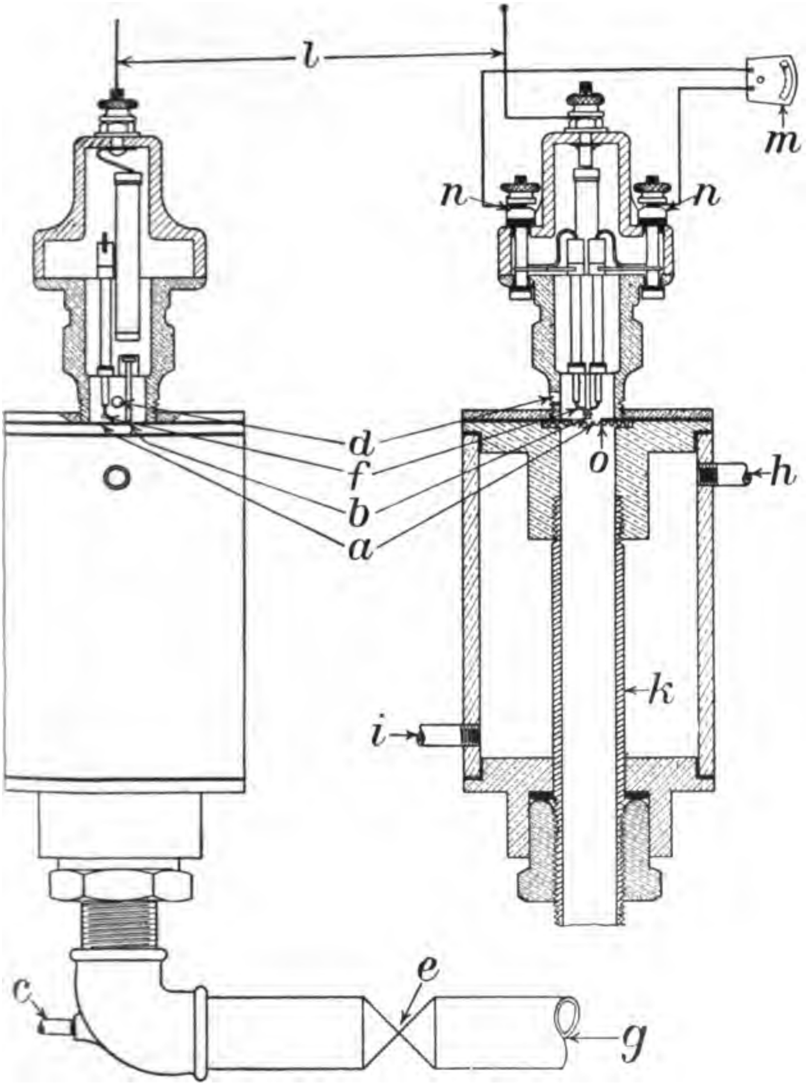


FIGURE 1.—Details of gas-percentage indicator. *a*, Point at which gas is burned; *b*, spark point; *c*, water-gage connection; *d*, vent for burned gas; *e*, control valve; *f*, thermocouple; *g*, gas intake; *h*, water-jacket discharge; *i*, water-jacket inlet; *k*, uptake tube; *l*, ignition wire; *m*, millivoltmeter; *n*, thermocouple terminal; *o*, double layer of gauze.

For the natural gas used this ratio is 8.6 per cent gas to 91.4 per cent air, and, as previously stated, this mixture is most sensitive to ignition.

The device was standardized by analysis of the mixtures that gave maximum voltmeter deflections. The results agreed closely with the theoretical value of 8.6 per cent gas. The standardizing was done in the chemical laboratory of the Bureau of Mines experiment station at Pittsburgh by G. A. Burrell, assistant chemist.

In making tests with percentages of gas greater or less than 8.6 the amount of gas required to give 8.6 per cent under the conditions of the test was first determined and then a proportional amount was used for the desired percentage. The results obtained by means of the device have been satisfactory and consistent, as is shown by the agreement of the pressures obtained in the tests. (See table, p. 10.)

RECORDING PRESSURE INDICATOR.

An indicator of the type used in taking cards on gas engines was connected to the motor casing near the relief valves. The indicator drum was wound against its spring and held in tension by a ratchet which was released by an electromagnet at the same time that the exploding spark was applied. By this arrangement a curve was obtained which resembled one-half of an indicator diagram taken on an engine. The curves are to be read from right to left; that is, the explosion is to be considered as beginning at the right-hand side of each diagram. This card showed the relative rate of propagation of the explosion as well as the maximum pressure developed within the motor casing. The maximum-pressure indication served as an excellent check upon the performance of the gas-percentage indicator.

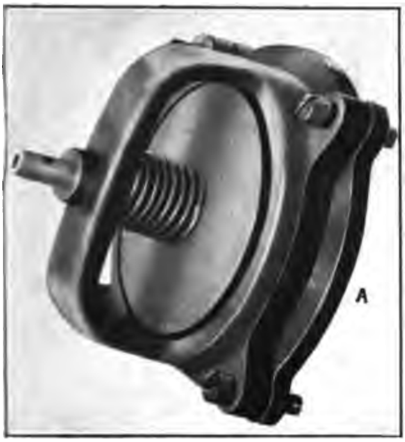
A gas-engine indicator, on account of the inertia of its moving parts, is not well suited to the observation of explosion pressures that vary rapidly over wide ranges. Although the results obtained gave all the information that was necessary for the purpose of the present investigation, it is doubtful whether the curves indicate the true variations of pressure, especially for the alternate positive and negative values recorded.

It was not considered necessary to perfect the drum-revolving mechanism so as to produce a uniform speed of rotation. The information that might have been obtained would have been interesting but was not indispensable to the investigation. Therefore the angular velocity of the drum was not made uniform and the time of rotation was not the same in all tests. The relative times of operation of the igniting spark and the drum release were also varied in order to obtain a more or less open curve at the point of maximum pressure.

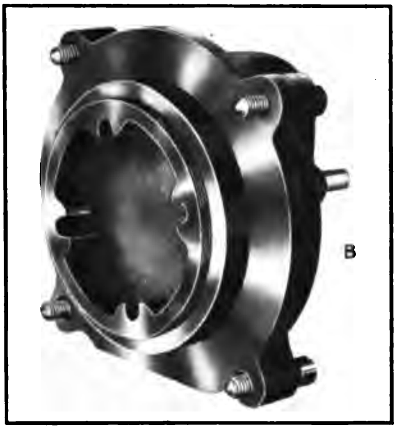
MEANS OF IGNITION.

The gaseous mixtures inside the motor casing were ignited sometimes by a spark from the brushes and sometimes by a gas-engine spark plug.

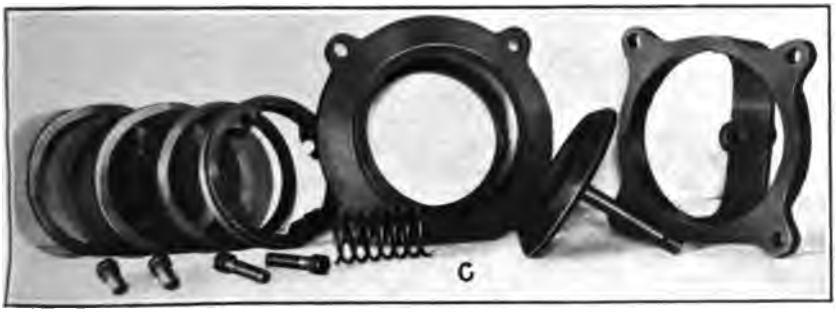
The latter method gave better control and, as comparative tests showed no difference in results obtained, was the means of ignition used in nearly all tests.



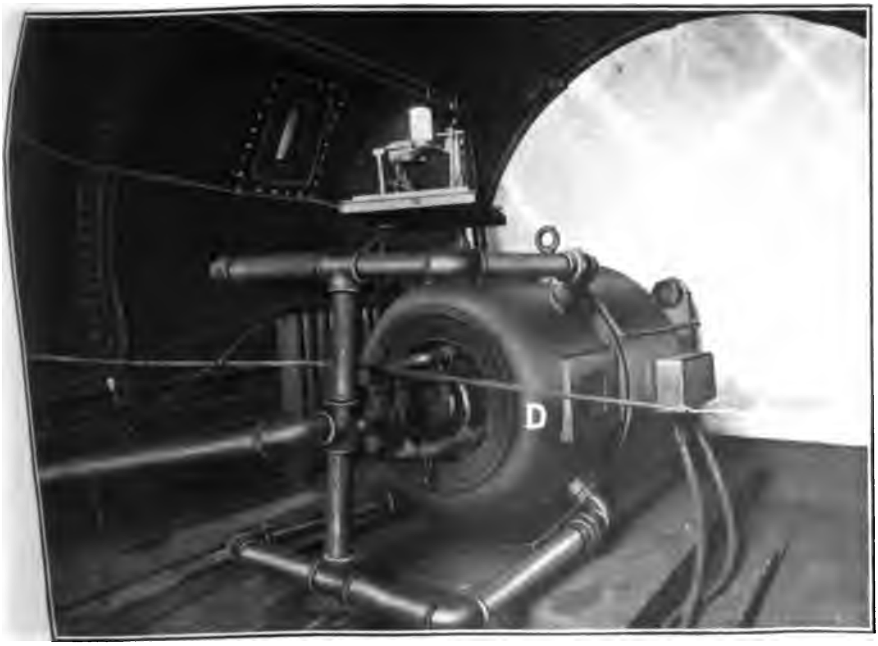
A. POPPET VALVE OF TYPE A PROTECTIVE DEVICE.



B. WIRE GAUZE OF TYPE A PROTECTIVE DEVICE.



C. MEMBERS OF TYPE A PROTECTIVE DEVICE.



D. MOTOR EQUIPPED WITH TYPE D PROTECTIVE DEVICE.

Several spark plugs were screwed into the motor casings at different points in order to determine the effect of initiating the explosion at points somewhat remote from the openings of the protective devices.

MOTOR PIPING.

In the earlier tests the pressures developed within the motor casing under presumably constant conditions varied in an annoying manner. The cause, which was not located for several months, proved to be the incomplete filling of the motor casing with the gaseous mixture. In the earlier tests only two openings in the motor casing were provided for the entrance of the gaseous mixture, and the pipe connecting the casing of the motor to the intake of the circulation fan was tapped into the former at only one point. As a result the gaseous mixture probably passed through the motor casing in a more or less defined stream and left corners and crevices unfilled with the explosive mixture.

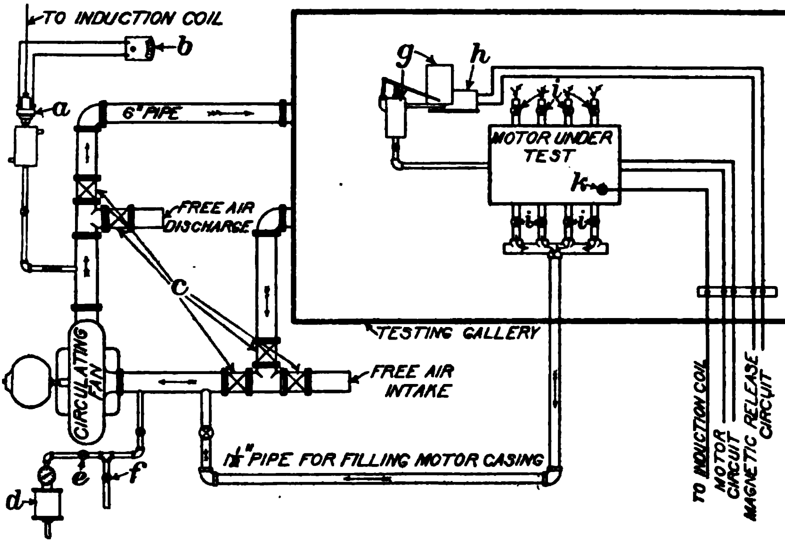


FIGURE 2.—Plan of testing apparatus: *a*, Gas-percentage indicator; *b*, millivoltmeter; *c*, 6-inch quick-closing gate valves; *d*, gas meter; *e*, gas-control valves; *f*, air-control valve; *g*, recording pressure indicator; *h*, release magnet for pressure indicator; *i*, 1½-inch quick-closing gate valves; *k*, spark plug for igniting mixture within casing.

The gas-percentage indicator showed that the mixture passing through the motor contained 8.6 per cent of gas, and for this reason attention was for some time diverted from the true cause of the variations in pressure. The trouble was finally eliminated by providing in the motor casing four to six openings for the entering gas and by tapping the motor casing at four points for connection to the intake of the circulating fan. All these openings had quick-closing gate valves for isolating the casing from the gallery air and all exterior piping before the application of the spark. Figure 2 shows the arrangement of the pipe connections.

TEST PROCEDURE.

GENERAL METHOD.

In testing the motors the casings were completely filled and surrounded with various mixtures of gas and air. The mixture within the casings was exploded by an electric spark, and the character and extent of the discharged products of combustion and their action upon the surrounding gaseous mixture were noted. Means were provided for measuring the pressure developed by an explosion within the casing.

Tests were made with various percentages of gas in the casing mixture, with and without coal dust in the protective devices, and with several different points of ignition. Tests were also made while the motors were running at rated speed. In some of the tests the casing mixture was ignited by a spark from the brushes. In other tests the mixture was ignited by a spark plug.

DETAILS OF OPERATION.

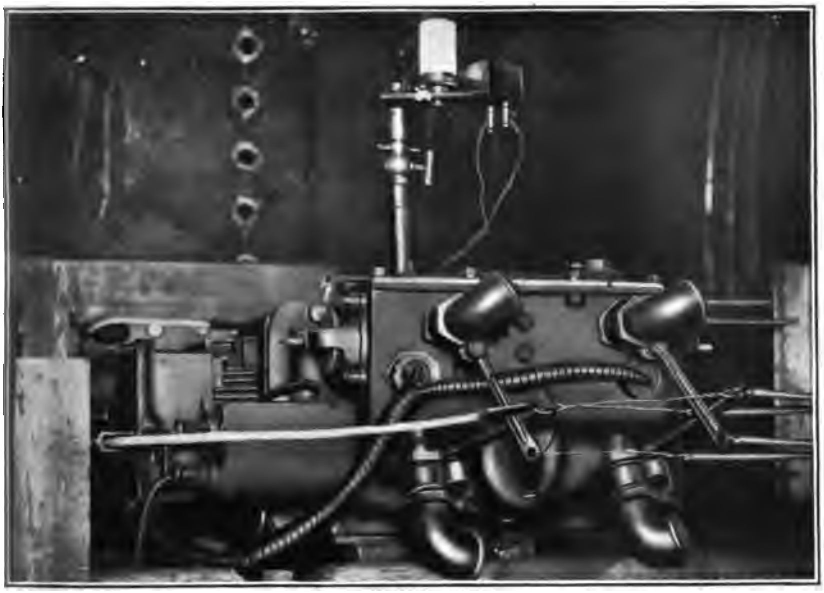
In making the tests arrangements were made for ignition at the desired point, a card was placed on the drum of the recording pressure indicator, and the gallery was closed. The circulating fan was then started and the valves set for circulating the mixture through the gallery. One hundred cubic feet of gas was then admitted to the gallery; the percentage indicator was then connected, and for several minutes the gas and air were mixed and circulated by the fan, gas being added as the indicator showed that it was required. The fan intake was then switched from the gallery piping to the pipe leading to the motor casing, and for several minutes the mixture was drawn into the casing and the percentage of gas was observed by the indicator. If the indicator showed that the proper mixture was not present, gas or air was added as needed.

If the gas-percentage indicator showed that the motor casing was properly "gassed," the gallery mixture was noted for one minute and then the mixture in the motor casing was noted for one minute more. If both gallery and casing mixtures proved to be correct, the fan was stopped and all valves leading to the gallery and to the motor casing were closed. The operator then took his position at the observation window directly above the motor and closed the switch that simultaneously ignited the mixture in the motor casing and released the drum of the recording pressure indicator.

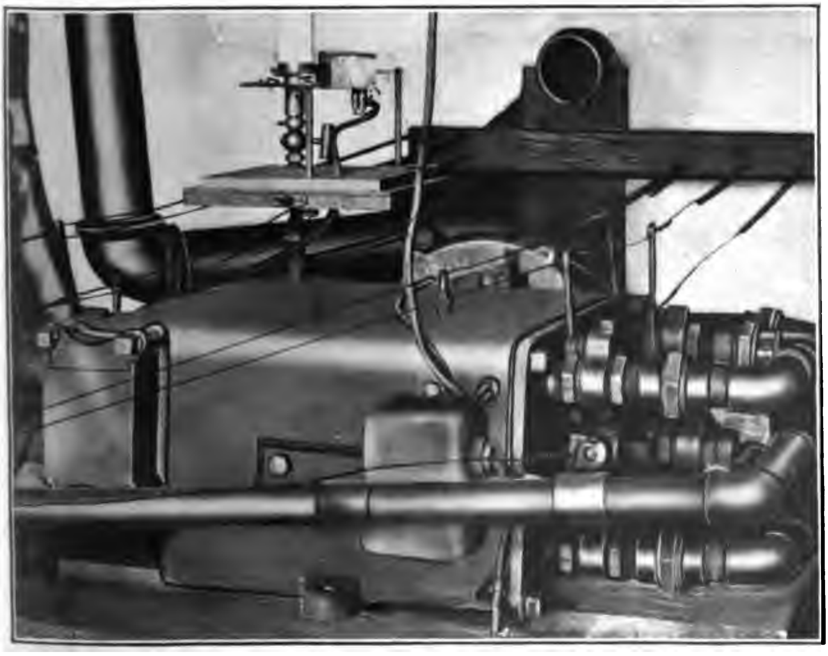
The gallery and the motor casing were thoroughly aired after each test.

PROTECTIVE DEVICES SUBMITTED.

For the purposes of this report the protective devices submitted for test have been classified under certain types, designated as type A, type B, etc. The characteristics of the various types are described below, and all test results are referred to the devices by the type letters.



A. MOTOR EQUIPPED WITH TYPE A PROTECTIVE DEVICE.



B. MOTOR EQUIPPED WITH TYPE E PROTECTIVE DEVICE.

TYPE A DEVICES.

The type A devices (Pl. III, *A*, *B*, and *C*, and fig. 3) consisted of three layers of gauze protected by a poppet valve. The motor used for testing was equipped with two of these devices, one of which was fastened to each side of that part of the motor casing that covered the commutator. (Pl. IV, *A*.)

TYPE B DEVICES.

The type B devices consisted of two unprotected layers of gauze having an exposed area of approximately 4 by 5½ inches. The motor that was submitted was provided with two of these devices, one of which was fastened to each side of that part of the motor casing that covered the commutator.

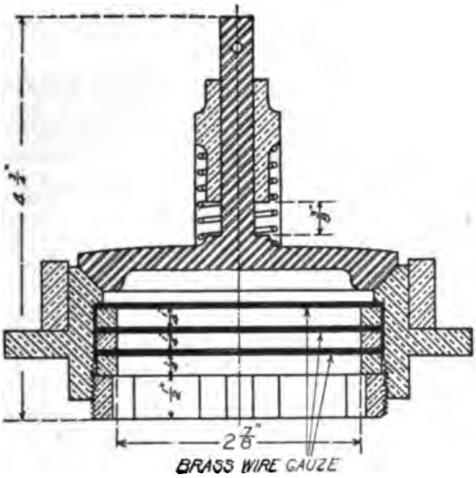


FIGURE 3.—Section of type A protective device.

TYPE C DEVICES.

The type C devices consisted of five brass baffle plates (Pl. V, *A* and *B*, and fig. 9). The motor tested was provided with two of these devices, one of which was fastened to the motor casing on each side of the bearing on the commutator end of the machine.

TYPE D DEVICES.

The type D devices consisted of two sets of plates, one of which was located at each end of the motor casing, as shown in Plate V, *C*. Each set contained 43 plates of sheet iron 1 mm. in thickness and spaced 1 mm. apart by small pieces of the material from which the plates were made. The plates were in the shape of flat rings having an inside diameter of 30 cm. and an outside diameter of 40 cm. The total relief area of each set at the inside edges of the plates was 24 square inches and at the outside edges 34 square inches.

TYPE E DEVICES.

The type E devices consisted of two sets of gauze and baffle plates, one of which was placed at each side of the motor casing at the commutator end, as shown in Plate IV, *B*. Each set consisted of five sheets of 30-mesh brass gauze 4½ by 6 inches, separated a distance of one-fourth inch by bronze spacers in each of which were 16 holes one-half by 1¾ inches. These sheets and spacers were inclosed by a bronze cover having a double baffle plate at the outlet (Pl. VI, *B*, *C*, and fig. 12). The whole was held to the motor casing by four ⅝-inch cap screws.

RESULTS OF TESTS.

In the description of the results of the tests each type of protection is considered separately. Following the individual reports is a general discussion of the investigation as a whole.

MEANING OF "PUNCTURE."

For the sake of simplicity and to avoid confusion, the term "puncture" has been applied to the ignition of the gaseous mixture surrounding a motor casing by flames discharged from it.[a] In any test results in which "puncture" is reported the protective devices failed to perform their safeguarding function, as evidenced by the fact that the gaseous mixture outside the motor was fired by flames from within.

TESTS OF TYPE A PROTECTIVE DEVICES.

The type A devices were the first ones tested and some of the tests were merely preliminary. The investigation of these devices would no doubt be carried on differently if it were to be repeated in the light of present knowledge.

The design of the devices made it necessary to test under an unusually large number of conditions. As there were moving parts, tests with the parts in various positions were essential.

One hundred and ninety-one tests were made on these devices under forty-five different conditions. Ten or more tests were made under each of ten conditions and not less than two tests under any condition.

In the following tabulation are enumerated the conditions surrounding each test, the maximum pressure developed within the motor casing, the number of tests made, and the number of "punctures" which took place. For each set of conditions a characteristic pressure card is shown in figures 4, 5, 6, and 7.

DETAILS.

The details of the type A protective devices are so clearly shown in Plate III, and figure 3 that description is not necessary. Plate IV, *A*, shows the location of the devices upon the motor frame.

MOTOR.

The motor to which the type A protective devices were attached was a 250-volt, compound-wound, totally inclosed, direct-current motor arranged for gear connection to a coal-cutting machine. It was guaranteed to deliver 24 horsepower for 30 minutes, with a maximum temperature rise of 75° C.

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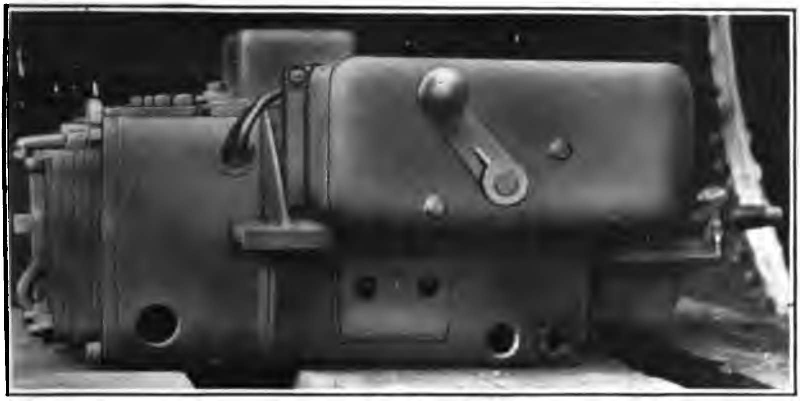
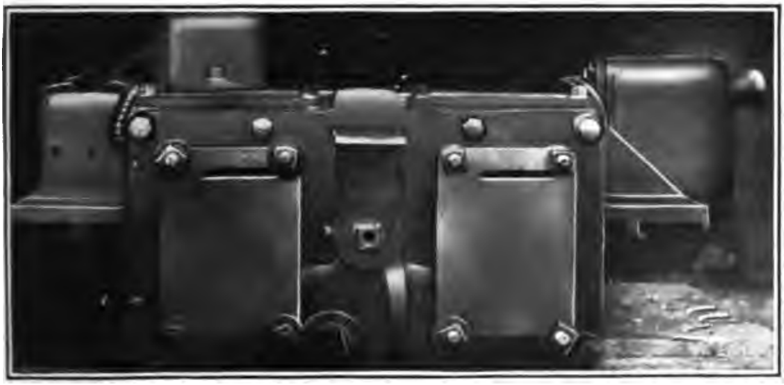
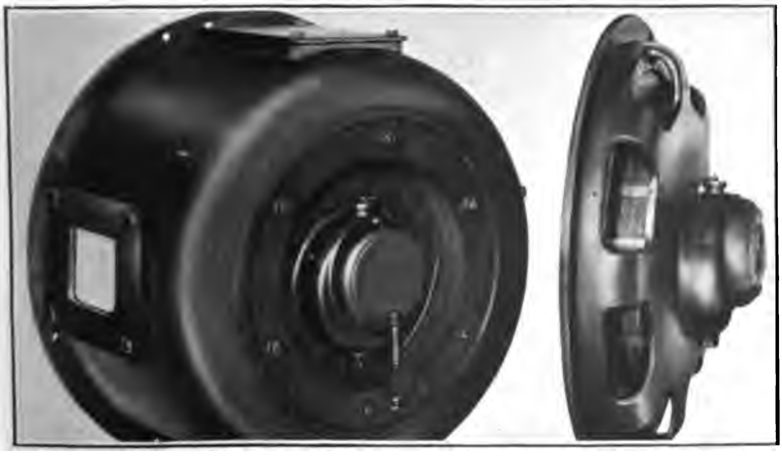
[a] This term has been used in the same sense by William Baum in his article "Fire-damp proof apparatus," General Electric Review, vol. 13, 1910, No. 9.



A. MOTOR EQUIPPED WITH TYPE C PROTECTIVE DEVICE, SHOWING FRONT VIEW OF BAFFLE PLATES.



B. SIDE VIEW OF THE MOTOR.



C. MOUNTING OF TYPE D PROTECTIVE DEVICE.

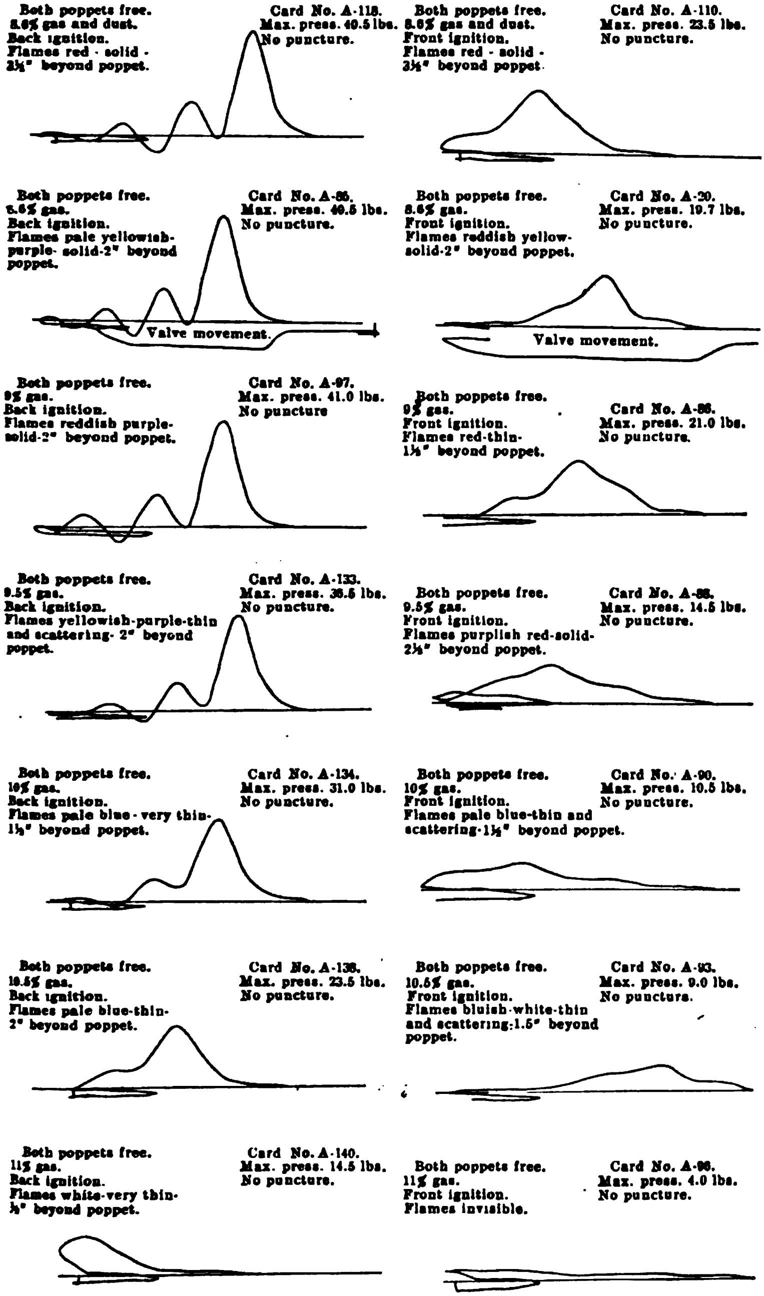
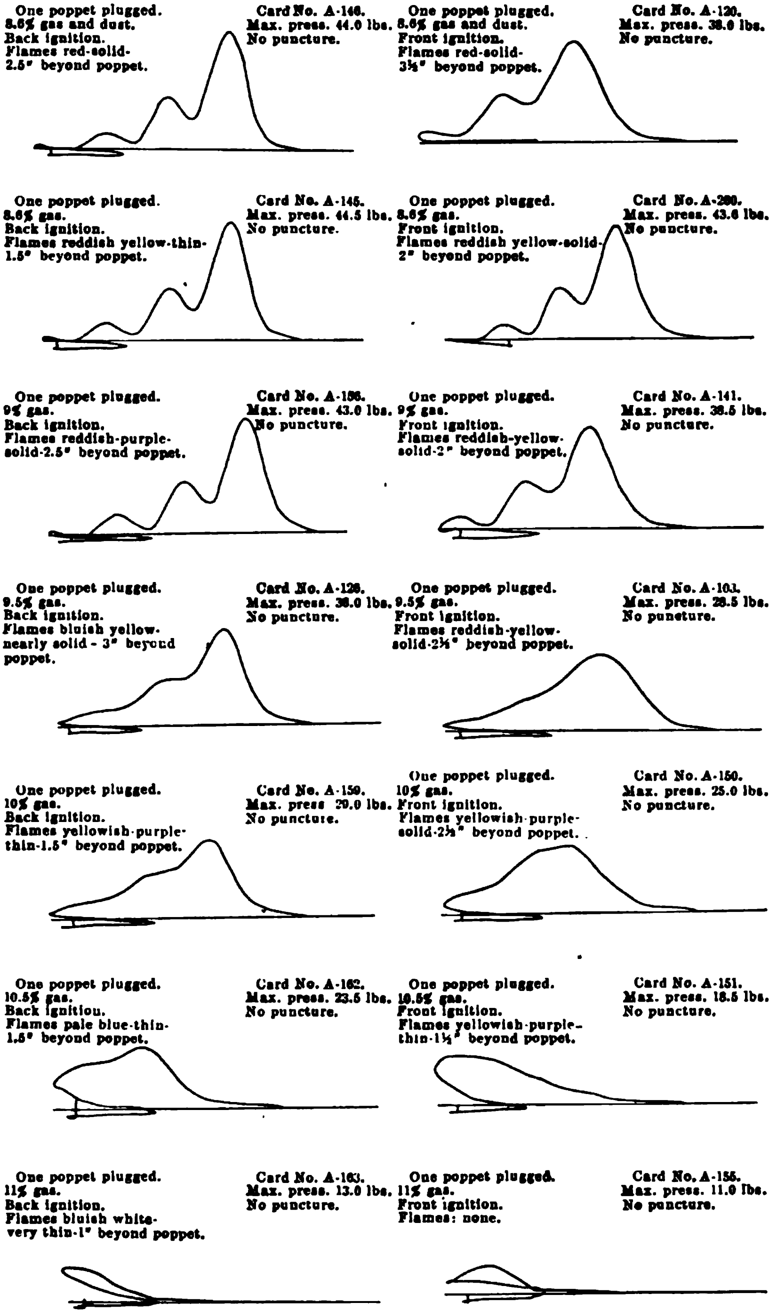


FIGURE 4.—Pressure diagrams for type A protective device.



One poppet plugged.
8.6% gas and dust.
Back ignition.
Flames red-solid-
2.5" beyond poppet.

Card No. A-146.
Max. press. 44.0 lbs.
No puncture.

One poppet plugged.
8.6% gas and dust.
Front ignition.
Flames red-solid-
3½" beyond poppet.

Card No. A-120.
Max. press. 38.0 lbs.
No puncture.

One poppet plugged.
8.6% gas.
Back ignition.
Flames reddish yellow-thin-
1.5" beyond poppet.

Card No. A-145.
Max. press. 44.5 lbs.
No puncture.

One poppet plugged.
8.6% gas.
Front ignition.
Flames reddish yellow-solid-
2" beyond poppet.

Card No. A-280.
Max. press. 43.6 lbs.
No puncture.

One poppet plugged.
9% gas.
Back ignition.
Flames reddish-purple-
solid-2.5" beyond poppet.

Card No. A-156.
Max. press. 43.0 lbs.
No puncture.

One poppet plugged.
9% gas.
Front ignition.
Flames reddish-yellow-
solid-2" beyond poppet.

Card No. A-141.
Max. press. 38.5 lbs.
No puncture.

One poppet plugged.
9.5% gas.
Back ignition.
Flames bluish yellow-
nearly solid - 3" beyond
poppet.

Card No. A-128.
Max. press. 38.0 lbs.
No puncture.

One poppet plugged.
9.5% gas.
Front ignition.
Flames reddish-yellow-
solid-2½" beyond poppet.

Card No. A-103.
Max. press. 28.5 lbs.
No puncture.

One poppet plugged.
10% gas.
Back ignition.
Flames yellowish-purple-
thin-1.5" beyond poppet.

Card No. A-159.
Max. press. 29.0 lbs.
No puncture.

One poppet plugged.
10% gas.
Front ignition.
Flames yellowish-purple-
solid-2½" beyond poppet.

Card No. A-150.
Max. press. 25.0 lbs.
No puncture.

One poppet plugged.
10.5% gas.
Back ignition.
Flames pale blue-thin-
1.5" beyond poppet.

Card No. A-162.
Max. press. 23.5 lbs.
No puncture.

One poppet plugged.
10.5% gas.
Front ignition.
Flames yellowish-purple-
thin-1½" beyond poppet.

Card No. A-151.
Max. press. 18.5 lbs.
No puncture.

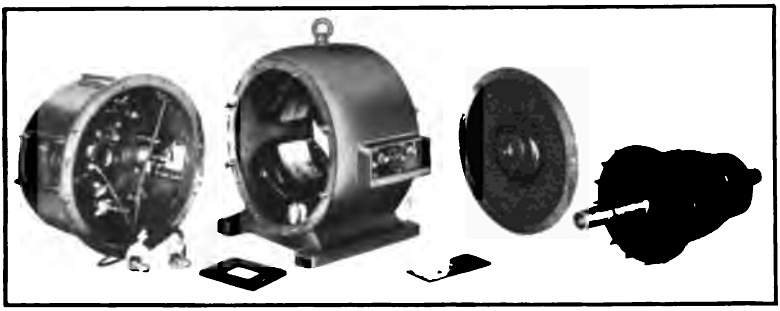
One poppet plugged.
11% gas.
Back ignition.
Flames bluish white-
very thin-1" beyond poppet.

Card No. A-163.
Max. press. 13.0 lbs.
No puncture.

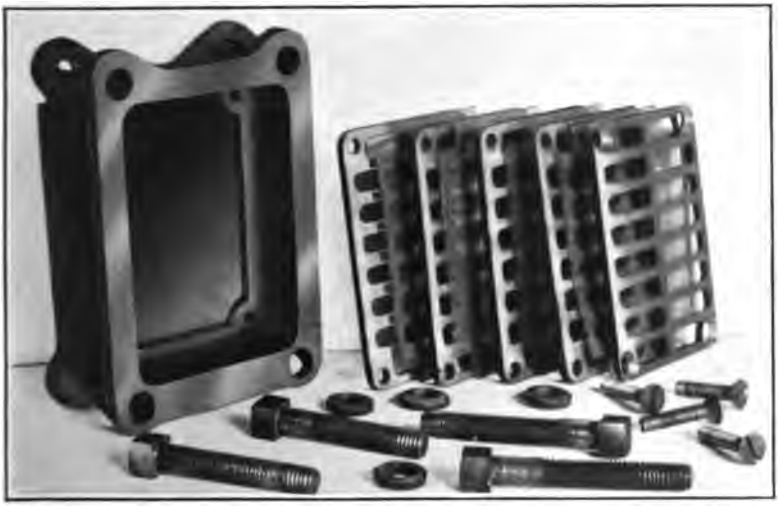
One poppet plugged.
11% gas.
Front ignition.
Flames: none.

Card No. A-155.
Max. press. 11.0 lbs.
No puncture.

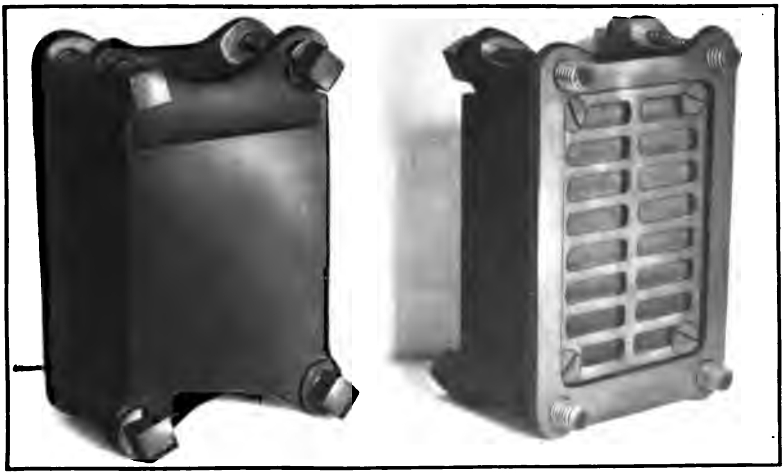
FIGURE 5.—Pressure diagrams for type A protective device.



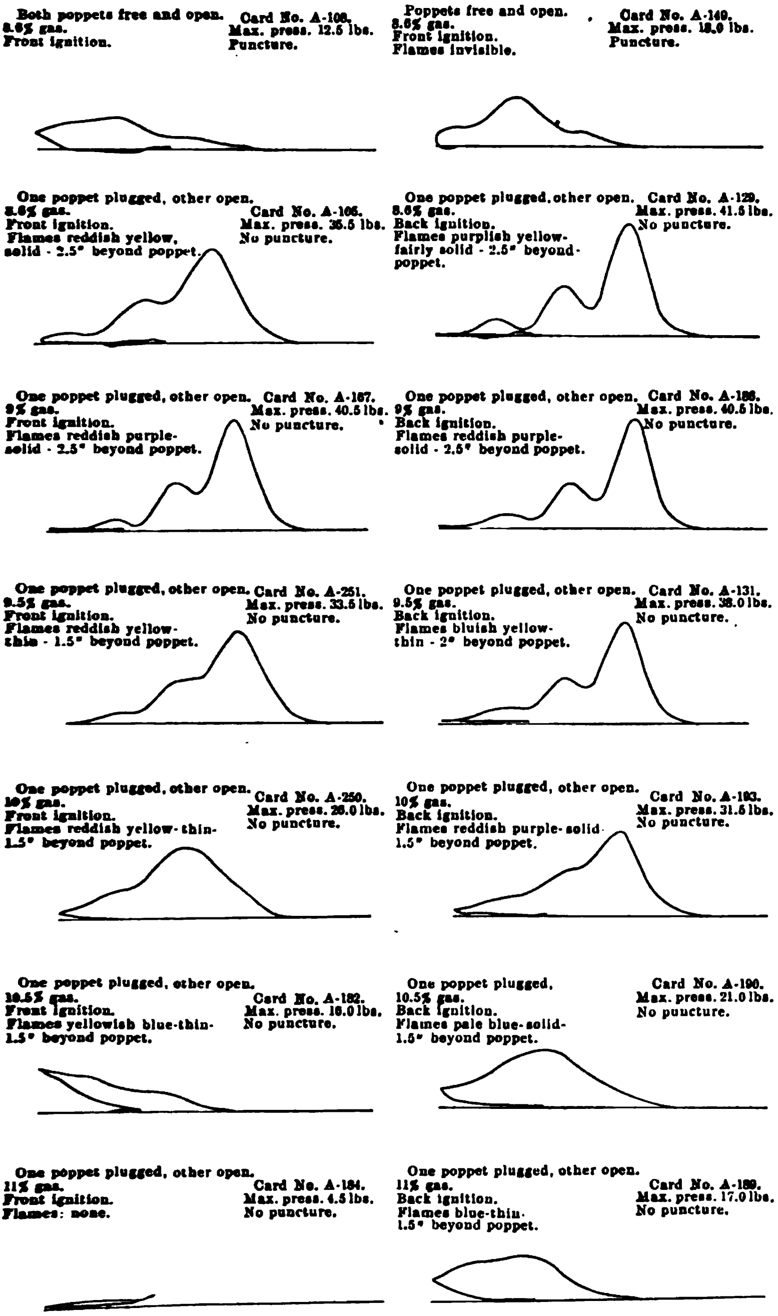
A. MEMBERS OF MOTOR USED WITH TYPE D PROTECTIVE DEVICE.



B. PARTS OF TYPE E PROTECTIVE DEVICE.



C. FRONT AND BACK OF TYPE E PROTECTIVE DEVICE.



Both poppets free and open.
8.6% gas.
Front ignition.
Card No. A-108.
Max. press. 12.5 lbs.
Puncture.

Poppets free and open.
8.6% gas.
Front ignition.
Flames invisible.
Card No. A-140.
Max. press. 18.0 lbs.
Puncture.

One poppet plugged, other open.
8.6% gas.
Front ignition.
Flames reddish yellow,
solid - 2.5" beyond poppet.
Card No. A-106.
Max. press. 35.5 lbs.
No puncture.

One poppet plugged, other open.
8.6% gas.
Back ignition.
Flames purplish yellow-
fairly solid - 2.5" beyond-
poppet.
Card No. A-129.
Max. press. 41.5 lbs.
No puncture.

One poppet plugged, other open.
9% gas.
Front ignition.
Flames reddish purple-
solid - 2.5" beyond poppet.
Card No. A-187.
Max. press. 40.5 lbs.
No puncture.

One poppet plugged, other open.
9% gas.
Back ignition.
Flames reddish purple-
solid - 2.5" beyond poppet.
Card No. A-188.
Max. press. 40.5 lbs.
No puncture.

One poppet plugged, other open.
9.5% gas.
Front ignition.
Flames reddish yellow-
thin - 1.5" beyond poppet.
Card No. A-251.
Max. press. 33.5 lbs.
No puncture.

One poppet plugged, other open.
9.5% gas.
Back ignition.
Flames bluish yellow-
thin - 2" beyond poppet.
Card No. A-131.
Max. press. 38.0 lbs.
No puncture.

One poppet plugged, other open.
10% gas.
Front ignition.
Flames reddish yellow-thin-
1.5" beyond poppet.
Card No. A-250.
Max. press. 26.0 lbs.
No puncture.

One poppet plugged, other open.
10% gas.
Back ignition.
Flames reddish purple-solid-
1.5" beyond poppet.
Card No. A-193.
Max. press. 31.5 lbs.
No puncture.

One poppet plugged, other open.
10.5% gas.
Front ignition.
Flames yellowish blue-thin-
1.5" beyond poppet.
Card No. A-182.
Max. press. 16.0 lbs.
No puncture.

One poppet plugged,
10.5% gas.
Back ignition.
Flames pale blue-solid-
1.5" beyond poppet.
Card No. A-190.
Max. press. 21.0 lbs.
No puncture.

One poppet plugged, other open.
11% gas.
Front ignition.
Flames: none.
Card No. A-184.
Max. press. 4.5 lbs.
No puncture.

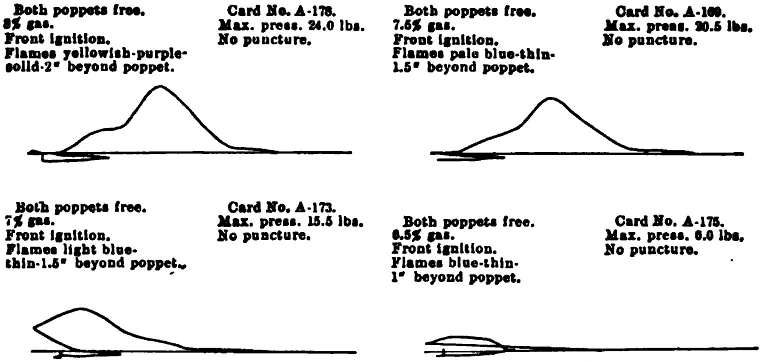
One poppet plugged, other open.
11% gas.
Back ignition.
Flames blue-thin-
1.5" beyond poppet.
Card No. A-189.
Max. press. 17.0 lbs.
No puncture.

FIGURE 6.—Pressure diagrams for type A protective device.

Connection to the service line was made with plug leads, the sockets for which were inclosed in an iron box attached to the motor frame. Upon the motor frame were also mounted an iron box containing a reversing switch and a similar box containing a starting switch, contacts, resistance, and a single-pole fuse. None of these boxes communicated with the interior of the motor casing; none of them was gas-tight, and none of them was provided with explosion-proof protective devices. All conductors entering these boxes or the motor casing passed through holes bushed with rubber or hard fiber.

The unoccupied space within the motor casing had a total volume of 1.2 cubic feet. The combined minimum area of the relief openings in the protective devices was 5.22 square inches.

The motor was at rest in all the tests recorded.


Both poppets free.
8% gas.
Front ignition.
Flames yellowish-purple-solid-2" beyond poppet.

Card No. A-178.
Max. press. 24.0 lbs.
No puncture.

Both poppets free.
7.5% gas.
Front ignition.
Flames pale blue-thin-1.5" beyond poppet.

Card No. A-169.
Max. press. 20.5 lbs.
No puncture.

Both poppets free.
7% gas.
Front ignition.
Flames light blue-thin-1.5" beyond poppet.

Card No. A-173.
Max. press. 15.5 lbs.
No puncture.

Both poppets free.
6.5% gas.
Front ignition.
Flames blue-thin-1" beyond poppet.

Card No. A-175.
Max. press. 6.0 lbs.
No puncture.

FIGURE 7.—Pressure diagrams for type A protective device.

IGNITION POINTS.

In the tabulated report, "Front ignition" refers to ignition from a spark plug screwed into the motor casing at a point directly above the commutator and near the protective devices. "Back ignition" refers to ignition from a similar spark plug screwed into the pinion end of the motor casing as far as possible from the protective devices.

POPPET CONDITION.

In the tabulation, under the heading "Poppet condition," the expression "both free" means that the poppet valves were closed but free to move as designed; "one plugged" means that one poppet valve was fastened in the closed position so that it could not move, whereas the other poppet was in its normal position and condition.

"Both free and open" means that the springs were removed from the valve stems and the poppets pulled open before the explosion within the motor casing was initiated. "One plugged, other open" means that one poppet valve was as specified under "one plugged," whereas the other was as specified under "both free and open."

FLAMES.

Flames were discharged through the protective devices in almost every test. Except in some of the "overgas" tests the flames were never less than 2 inches in length and often were longer. The maximum flame length was about 4 inches. The flames lasted only a fraction of a second and varied in color from pale blue to bright red.

TABLE 1.—*Results of tests of type A protective devices.*

Group No.	Poppet condition.	Gas percentage.	Ignition point.	Maximum pressure.	Outside flames.	Typical pressure diagram.		Number of tests made.	Number of "punctures."
						Card number.	Figure number.		
				Pounds per sq. in.					
1	Both free......	8.6	Front...	23.0	Yes.....	A-20	4	15	0
2	.....do........	8.6	Back....	43.5	Yes.....	A-85	4	12	0
3	.....do........	9.0	Front...	21.0	Yes.....	A-86	4	2	0
4	.....do........	9.5	...do....	14.5	Yes.....	A-88	4	2	0
5	.....do........	10.0	...do....	11.0	Yes.....	A-90	4	2	0
6	.....do........	10.5	...do....	9.0	Yes.....	A-93	4	2	0
7	.....do........	11.0	...do....	4.5	Yes.....	A-96	4	2	0
8	.....do........	9.0	Back....	41.0	Yes.....	A-97	4	2	0
9	.....do........	9.5	...do....	36.5	Yes.....	A-133	4	2	0
10	.....do........	10.0	...do....	31.0	Yes.....	A-134	4	2	0
11	.....do........	10.5	...do....	25.0	Yes.....	A-138	4	3	0
12	.....do........	11.0	...do....	18.0	Yes.....	A-140	4	3	0
13	.....do........	8.0	Front...	24.0	Yes.....	A-178	7	3	0
14	.....do........	7.5	...do....	23.0	Yes.....	A-169	7	3	0
15	.....do........	7.0	...do....	16.0	Yes.....	A-173	7	3	0
16	.....do........	6.5	...do....	7.5	Yes.....	A-175	7	2	0
17	.....do........	[a]8.6	...do....	27.5	Yes.....	A-110	4	10	[b]1
18	.....do........	[a]8.6	Back....	45.8	Yes.....	A-118	4	10	0
19	One plugged..	8.6	Front...	43.0	Yes.....	A-260	5	10	0
20	.....do........	8.6	Back....	44.5	Yes.....	A-145	5	10	0
21	.....do........	9.0	Front...	38.5	Yes.....	A-141	5	2	0
22	.....do........	9.5	...do....	30.0	Yes.....	A-108	5	3	0
23	.....do........	10.0	...do....	25.0	Yes.....	A-150	5	2	0
24	.....do........	10.5	...do....	18.5	Yes.....	A-151	5	2	0
25	.....do........	11.0	...do....	11.0	No......	A-155	5	2	0
26	.....do........	9.0	Back....	43.0	Yes.....	A-156	5	2	0
27	.....do........	9.5	...do....	38.0	Yes.....	A-126	5	2	0
28	.....do........	10.0	...do....	33.0	Yes.....	A-159	5	4	0
29	.....do........	10.5	...do....	25.0	Yes.....	A-162	5	2	0
30	.....do........	11.0	...do....	14.5	Yes.....	A-163	5	2	0
31	.....do........	[a]8.6	Front...	47.0	Yes.....	A-120	5	10	0
32	.....do........	[a]8.6	Back....	47.0	Yes.....	A-146	5	12	0
33	Both free and open.	8.6	Front...	18.0	Yes.....	A-108	6	3	3
34	One plugged, other open.	8.6	...do....	37.5	Yes.....	A-105	6	10	0
35	.....do........	8.6	Back....	45.5	Yes.....	A-129	6	10	0
36	.....do........	9.0	Front...	40.5	Yes.....	A-167	6	2	0
37	.....do........	9.5	...do....	33.5	Yes.....	A-251	6	3	0
38	.....do........	10.0	...do....	30.5	Yes.....	A-250	6	5	1
39	.....do........	10.5	...do....	16.0	Yes.....	A-182	6	2	0
40	.....do........	11.0	...do....	4.5	No......	A-184	6	2	0
41	.....do........	9.0	Back....	41.0	Yes.....	A-186	6	2	0
42	.....do........	9.5	...do....	39.0	Yes.....	A-131	6	2	0
43	.....do........	10.0	...do....	31.5	Yes.....	A-193	6	2	0
44	.....do........	10.5	...do....	21.0	Yes.....	A-190	6	2	0
45	.....do........	11.0	...do....	17.5	Yes.....	A-189	6	2	0

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[a] In this group of tests the figures in the column headed "gas percentages" are self-explanatory with the exception of "8.6 and dust." This means that finely ground coal dust was sifted into the protected devices before each test.

[b] The test in which "puncture" occurred was conducted in the same manner as the other nine tests of this series. The usual explosion inside the motor casing took place without causing a "puncture." All electrical connections with the motor casing were then broken and after an interval of several seconds the operator opened the quick-closing valves, by which the casing was filled with gas. The gallery exploded instantly. This "puncture" can not be charged against the protective devices, but is of interest as seeming to indicate that the presence of coal dust was its immediate cause. Probably the coal dust within the motor casing, although ignited by the explosion, could not burn because of the lack of oxygen. When this lack was supplied by the opening of the "gassing" valves, the coal dust took fire and ignited the gas in the gallery.

DISCUSSION OF TEST RESULTS.

GENERAL REVIEW.

Of 45 sets of conditions assumed, group 33 produced "punctures" in each of three tests made, and group 17 produced a single "puncture" out of ten tests made. During the earlier part of the investigation a "puncture" was obtained under the same conditions that prevailed in group 1, except that the percentage of gas in the motor casing could not be definitely determined, although it was known to be less than 8.6 per cent. No "puncture" that could be charged to defects in the design of the protective devices was produced in the 182 tests of the remaining 43 groups.

With the relief valves in their normal condition no "puncture" happened in any of the 80 tests in which the conditions were known and controlled, but one "puncture" happened under indeterminate conditions, as mentioned above.

PERFORMANCE OF THE DEVICES.

In order to produce an explosion outside a motor casing the gases discharged from the protective devices must raise the surrounding gaseous mixture to its ignition temperature. If in the tests the gases were discharged at a temperature lower than the ignition temperature of the gas—that is, if the protective devices fulfilled the function for which they were designed—no explosion could have taken place outside the motor regardless of how much heat was discharged. The presence of flames, however, showed that the temperature of the discharged gases was higher than the ignition temperature of the gaseous mixture surrounding the motor. Consequently, the temperature of the discharged gases must have been reduced by radiation to the surrounding gas without raising the latter to its ignition temperature, or "puncture" would have occurred.

The safety of a motor protected as in these tests, therefore, appears to depend upon the efficient dissipation of heat in the gaseous mixture surrounding the motor instead of upon the removal of the heat from the escaping gas by the protective devices; the gauzes obviously fail in their cooling functions since they do not prevent the passage of flames; therefore it is probable that even when no "puncture" occurs the escaping gases fail to ignite the surrounding mixture by only a small margin which might be overstepped by a slight variation in conditions.

The poppet probably assists in cooling the escaping gases by discharging them in a manner most conducive to rapid loss of heat, and it also serves to equalize the pressure on each side of the gauzes which would otherwise be torn from their fastenings by the explosion within the casing.

The unprotected parts of the relief valves are exposed to injury from falling material and careless handling, and, being easily accessible, are likely to be put out of adjustment through ignorance or carelessness.

THE EXPLOSIVE CONDITION.

The gaseous mixture that produces the most heat when burned contains 8.6 parts of gas and 91.4 parts of air. The greatest temperature and pressure is produced when such a mixture is burned or exploded most rapidly. The greatest amount of heat is discharged at one point when the gases are made to escape through a single protective device.

All the above conditions existed in the group 20 tests and yet "puncture" did not take place, although only one protective device was in service.

In each of the group 33 tests, with both protective devices in service, "puncture" occurred. The total heat produced was a maximum, but the temperature and pressure were both lower than in the group 20 tests.

In the group 35 tests the position of the poppet was the same as in the group 33 tests. The total heat was also the same, the temperature and pressure were higher, and the hot gases were vented through a single protective device, yet there was no "puncture." Card No. A–20 (fig. 4) shows that almost as soon as the explosion within the motor casing started the poppets moved to the same position that they occupied in the group 33 tests. It therefore appears that the conditions of radiation were better in the tests of group 35 than in those of group 33, probably because of the more rapid expansion of the discharged gases as they left the motor casing. In the single instance mentioned (p. 24) both poppets were closed and yet explosion occurred, In the group 38 tests the heat developed was not a maximum, yet one test gave an explosion with 10 per cent gas.

Since explosions occurred with poppets open, with poppets closed, with 8.6 per cent gas, with "overgas," with "undergas," with low pressure (12.5 pounds), and with comparatively high pressure (30.5 pounds), it is not possible exactly to define what constitutes the explosive condition for the type A protective device as applied to the particular motor tested.

STARTING BOX AND CONNECTIONS.

With safety devices on the motor casing it is hardly consistent to leave the starting box unprotected. A spark sufficiently large to ignite gas may be drawn every time the motor is started, and if gas is present the heat due to its explosion must be absorbed by something if ignition of surrounding gas is to be prevented.

Although it is not likely that the main connection plugs would be removed while current is passing through them, there is no absolute assurance to the contrary unless they are interlocked in a suitable manner with the starting switch.

TESTS OF TYPE B PROTECTIVE DEVICES.

The type B devices were not tested in the gallery because the information gathered from the test of the type A devices pointed to the almost certain failure of the type B protection. This consideration alone would have been insufficient to exclude the type B devices from test had the inadequacy of mechanical design of the devices not been manifest. Under the conditions that would surround such devices in practice, so large an area of unprotected gauze would be in danger of injury that would render the gauze of no avail as a safety device. The bureau's opinion was communicated to the manufacturers, who promptly withdrew their devices.

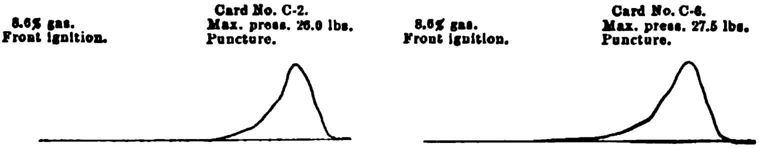

FIGURE 8.—Pressure diagrams for type C protective device.

TESTS OF TYPE C PROTECTIVE DEVICES.

The design of the type C devices was such that their failure was almost a certainty, but as the mechanical design was rugged the devices were submitted to a few tests in order to prove beyond a doubt that the devices were not suited to the purpose for which they were intended.

Only two tests were made upon these devices. The results of these tests were so conclusive that further investigation was considered unnecessary.

In the following tabulation are enumerated the conditions surrounding each test, the maximum pressure developed within the casing, the number of tests made, and the number of "punctures" which took place. For each test a characteristic pressure card is shown in figure 8.

DETAILS.

The details of the type C protective devices are shown in Plate V, *A* and *B*, and figure 9.

Each of these devices consisted of five brass baffle plates so disposed as to make a passage approximately 28 inches long with a cross-section of 4 inches by ¼ inch. This passage interposed three return bends and two right-angle bends in the path of the flame.

MOTOR.

The motor to which the type C protective devices were attached was a 250-volt, compound-wound, totally inclosed, direct-current motor arranged for gear connection to a coal-cutting machine. It was guaranteed to deliver 20 horsepower for 30 minutes, with a maximum temperature rise of 75° C.

Connection to the service line was made by leads provided with brass lugs for fastening to studs set in a wooden block on the outside of the motor casing. Studs and block were protected by a cast-iron cover bolted to the casing. Upon the motor frame was also mounted an iron box containing the starting switch, contacts, resistances, and a single-pole fuse. The box did not communicate with the interior of the motor casing. All conductors entering the box or the motor casing were bushed with fiber. The starting box was not provided with explosion-proof devices.

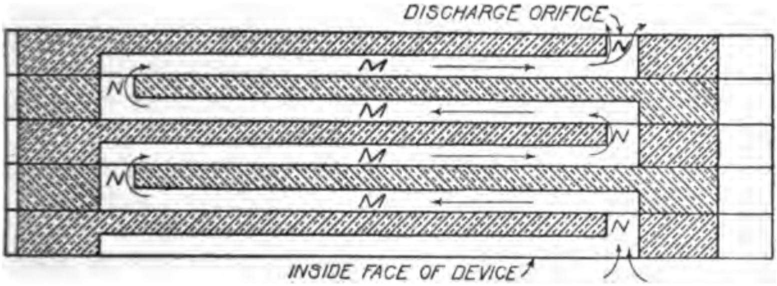

FIGURE 9.—Section of type C protective device. Area of cross section of opening at $M=1$ square inch; area of cross section of opening at $N=1\frac{1}{2}$ square inches.

The unoccupied space within the motor casing had a total volume of 0.68 cubic foot. The combined minimum area of the discharge passages in the protective devices was 2 square inches.

TEST CONDITIONS.

These tests were made with a mixture containing 8.6 per cent gas; the motor was at rest. The mixture inside the motor casing was ignited from a spark plug screwed into the casing at a point directly above the commutator and near the protective devices.

TABLE 2.—*Results of tests of type C protective devices.*

Group No.	Motor condition.	Gas percentage.	Ignition point.	Maximum pressure.	Outside flames.	Card No.[a]	Number of tests made.	Number of punctures.
1	At rest..	8.6	Front...	27.5	Yes.....	C-2 C-6	2	2

[a] See fig. 8.

DISCUSSION OF TEST RESULTS.

As a result of the tests the following conclusions are presented:

The type C protective device is not a safe design because the openings in the baffle plates are so large that their cooling effect is negligible and flames can easily pass through them. If gas is in the motor casing, the spaces between the baffle plates will also be filled with the mixture, as most of the gas will enter through these openings. Under such circumstances flame from within the motor casing will readily pass throughout the entire length of the passage between the baffle plates, being fed as it advances by the gas between the plates. Multiplication of the baffle plates would not improve the safety of the device.

TESTS OF THE TYPE D PROTECTIVE DEVICES.

Two hundred and thirty-six tests were made upon the type D devices under 25 different conditions. Ten or more tests were made for every condition in which the results of fewer tests were not conclusive. A smaller number of tests was made with the motor running, because the results were conclusive and because these tests were so severe that it was feared that the windings would break down before all the desired tests could be made.

Although the tests were made with great care, it was found impossible to check all pressures exactly, especially in "undergas" and "overgas" tests. Consequently, enough tests were made to obtain a sufficient number that checked consistently, and these are the only ones that are included in this report, as the other tests, being taken under unsatisfactory conditions, could add no information.

In the tabulation following are enumerated the conditions surrounding each test, the maximum pressure developed within the motor casing, the number of tests made, and the number of "punctures" that took place. For each set of conditions a characteristic pressure card is shown in figures 10 and 11.

DETAILS.

The details of the type D protective devices are clearly shown in Plates VI, *A*, and V, *C*, and the devices are described upon page 17. Plate III, *D*, shows how these devices are attached to the motor frame.

MOTOR.

The motor to which the type D protective device was attached was a 250-volt, 4-pole, shunt-wound, totally inclosed, direct-current motor, arranged for belt or direct connection to its load. The motor was guaranteed to deliver 10 horsepower continuously, with 40° C. rise in temperature, and was designed for general power purposes. No starting device was submitted for test with this machine. The

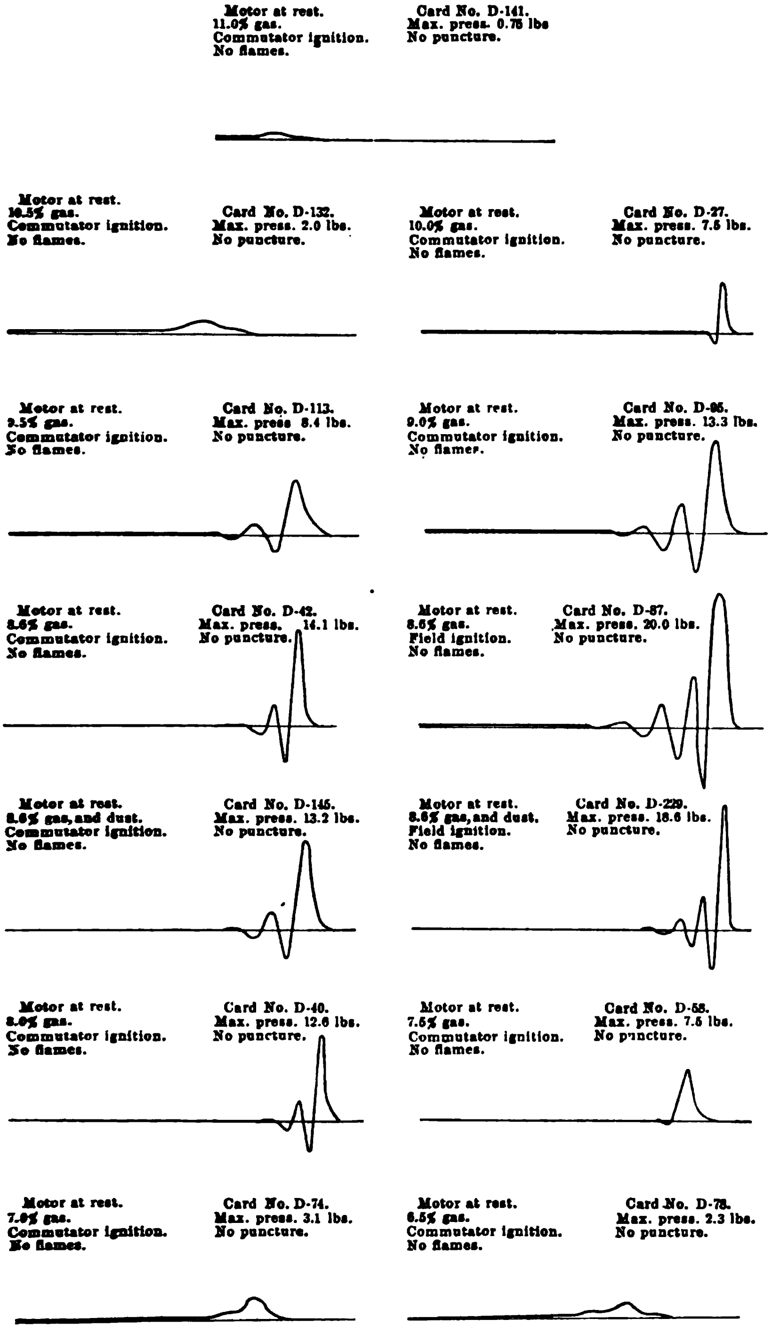

FIGURE 10.—Pressure diagrams for type D protective device.

unoccupied space within the motor casing had a total volume of 5.1 cubic feet. The combined minimum area of the relief openings was 48 square inches.

Connection with the service line was made to studs inclosed in an iron terminal box which was rigidly attached to the motor frame.

The leads from the service line were brought into the bottom of the terminal box through unbushed holes and soldered to brass lugs drilled to fit the studs, to which they were fastened by a single nut. The studs passed through fiber bushings in the motor frame. The inner ends of the studs were protected by recessed porcelain blocks. The terminal box was not designed to be gas-tight. There was no communicating passage between the terminal box and the interior of the motor casing.

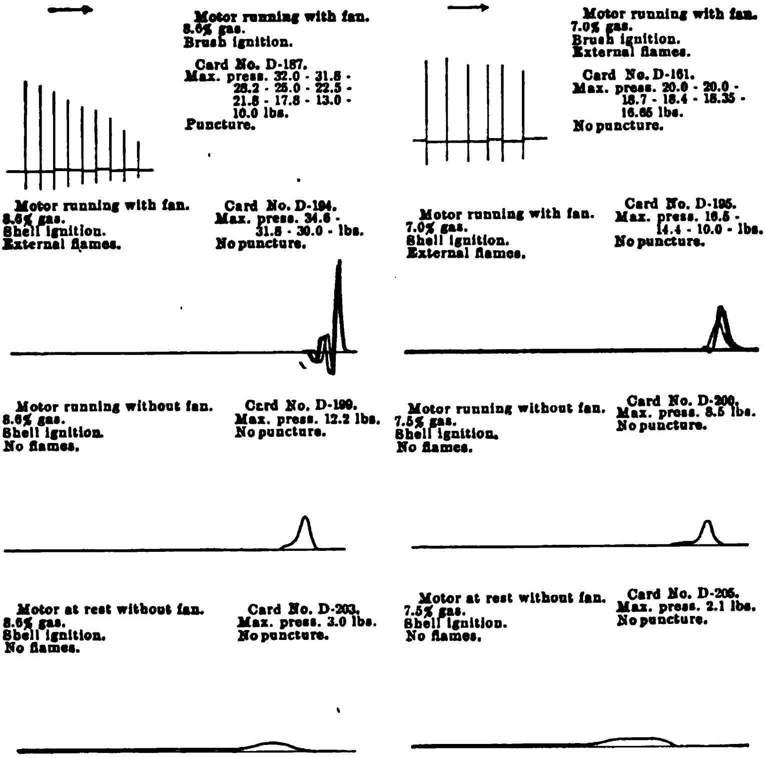

FIGURE 11.—Pressure diagrams for type D protective device.

The armature shaft carried a fan (Pl. VI, *A*) so disposed with reference to the relief openings as to cause a considerable circulation of air through the motor casing when the armature was revolving at its rated speed. The fan consisted of 16 flat blades, 2½ by 1½ inches, mounted radially and in planes passing through the axis of rotation. The diameter inside the blades was 11½ inches. The outside diameter was 16½ inches.

On either side of the commutator a window of plate glass was fastened to the motor casing (Pl. VI, *A*). These windows were seemingly provided to permit the observation of brush sparking without opening the motor casing. One of the windows was cracked when the motor was received, but withstood the tests without further damage.

IGNITION POINTS.

In the tabulated report "commutator ignition" refers to ignition from a spark plug fastened near the commutator. "Shell ignition" refers to ignition from a spark plug screwed through the motor-casing at a point directly over the commutator. "Field ignition" refers to ignition at a point between the upper field coils near the commutator end of the armature core. "Brush ignition" refers to ignition by sparks from the brushes while the motor was running.

FLAMES.

Flames were discharged through the protective devices in all tests in which the motor was running with the fan in place, but no outside flames were observed in any other tests.

"AFTER-BURNING."

The term "after-burning," as used in this report, is applied to the appearance of flame at the inside edges of the protective plates from the burning of a gaseous mixture not within the casing at the time of the explosion. In "after-burning," gas was either drawn into the motor by the fan when the motor was running or forced in by atmospheric pressure as the dead gases within the motor casing cooled.

Fresh gas entered the casing after each explosion, whether the motor was running or not, but its subsequent ignition appeared to depend upon a delicate balance of several variables. Its bearing upon the safety of the motor submitted is not considered important, as it never occurred when the motor was running with the fan in place, and lasted only a few seconds when the motor was at rest.

TABLE 3.—*Results of tests of type D protective devices.*

Group No.	Motor condition.	Gas per-centage.	Ignition point.	Maxi-mum pres-sure.	Out-side flames.	Typical pressure diagram.		Num-ber of tests made.	Num-ber of "punc-tures."	Speed of motor.
						Card No.	Figure No.			
				Lbs. per sq. in.						*R.P.M.*
1	At rest, with fan.	8.6	Commutator..	14.1	No....	D-42	10	11	0	0
2	...do.......	8.6	Field..........	20.0	No....	D-87	10	13	0	0
3	...do.......	[a]8.6	Commutator..	13.2	No....	D-145	10	10	0	0
4	...do.......	[a]8.6	Field..........	18.6	No....	D-229	10	11	0	0
5	...do.......	9.0	Commutator..	13.3	No....	D-95	10	10	0	0
6	...do.......	9.5	.....do.........	8.4	No....	D-113	10	10	0	0
7	...do.......	10.0	.....do.........	7.5	No....	D-27	10	11	0	0
8	...do.......	10.5	.....do.........	2.5	No....	D-132	10	10	0	0
9	...do.......	11.0	.....do.........	0.8	No....	D-141	10	10	0	0
10	...do.......	8.0	.....do.........	12.6	No....	D-40	0	10	0	0
11	...do.......	7.5	.....do.........	7.7	No....	D-58	10	10	0	0
12	...do.......	7.0	.....do.........	3.1	No....	D-74	10	10	0	0
13	...do.......	6.5	.....do.........	2.3	No....	D-78	10	11	0	0
14	At rest, without fan.	8.6	Shell..........	3.0	No[b]...	D-203	11	2	0	0
15	...do.......	7.5	.....do.........	2.1	No[b]...	D-205	11	2	0	0
16	Running, with fan.	8.6	Brush.........	32.1	Yes...	D-187	11	9	2	[c]1,250
17	...do.......	7.0	.....do.........	20.0	Yes...	D-161	11	1	0	[c]1,250
18	...do.......	8.6	Shell..........	24.0	Yes...	D-194	11	1	0	[c]1,250
19	...do.......	8.6	.....do.........	29.6	Yes...	D-194	11	1	0	1,510
20	...do.......	8.6	.....do.........	34.6	Yes...	D-194	11	1	0	1,790
21	...do.......	7.0	.....do.........	16.5	Yes...	D-195	11	1	0	1,250
22	...do.......	6.5	.....do.........	11.2	Yes...	D-195	11	1	0	1,250
23	Running, without fan.	8.6	.....do.........	12.4	No[d]...	D-199	11	2	0	1,250
24	...do.......	8.6	.....do.........	12.2	No[d]...	D-199	11	1	0	1,500
25	...do.......	7.5	.....do.........	8.5	No....	D-200	11	1	0	1,250

[a] In this group of tests finely ground coal dust was sifted between the plates of the protective devices before each test.
[b] After-burning started at once and lasted for about 15 seconds.
[c] Normal speed.
[d] After-burning started at once and continued as long as the motor was running. Current was cut off the motor as soon as the explosion took place, but the motor did not stop for nearly a minute.

DISCUSSION OF TEST RESULTS.

GENERAL REVIEW.

One hundred and forty-one satisfactory tests were made with the motor at rest, and in none of these tests did "puncture" take place.

Thirteen tests were made with the motor running at normal speed with the fan in place. "Puncture" occurred in two of these tests, and probably would have taken place in at least three others if the tests had been continued to the limit.

Four tests were made with the motor running without fan. "Puncture" did not occur in any of these tests, but "after-burning" began immediately after the explosion, and would have continued indefinitely if the motor had not been stopped. The continuance of "after-burning" would have soon burned the insulation from the armature coils; but that the plates would have become sufficiently heated to allow the flame to pass out against the entering gas current is not certain.

In four tests, made with the motor at rest and the fan removed from the casing, there was no puncture nor were there external flames. The maximum pressure developed within the motor casing was only 3 pounds. "After-burning" followed the explosion, but lasted only a few seconds as the motor was not running.

Two tests were made with the fan in place and the motor running at greater than normal speed. "Puncture" did not occur in either of these tests, in each of which there were only three explosions within the motor casing.

PERFORMANCE OF THE DEVICES.

The protective devices appeared to be adequate for all conditions prevailing when the motor was at rest or when the motor was running without the fan, as under neither of these conditions were flames discharged through the protective devices.

When the motor was operating with the fan in position, reddish-yellow flames 4 to 6 inches in length were discharged through the protective devices at the commutator end.

The duration of these flames was short, and this probably accounted for their failure invariably to ignite the surrounding gaseous mixture, unless, perhaps, the first gases discharged from the casing were cooled by the plates below the ignition temperature of methane and drove away the explosive mixture immediately surrounding the relief openings, so that the flames which issued later were discharged into dead gas.

Despite the fact that there was no "puncture" until after at least five successive explosions inside the casing, "puncture" would almost surely occur in time if a sufficient supply of gaseous mixture were available.

If the motor were to be designed to operate without a fan, "after-burning" sufficient to destroy the insulation would take place if the rotation of the armature should produce a circulation of gas through the casing.

The value of this form of protection may be entirely destroyed by separating the plates by a small fraction of an inch. In the device tested the edges of the plates were not sufficiently protected from possible injuries of this character.

EFFECT OF THE FAN.

When the fan was in operation, it increased the effective resistance of the pulley end relief openings to the discharge of the products of explosion. This gave rise to higher pressures within the casing, and also caused more heat to be discharged from the commutator end openings. The fan also refilled the casing with the gaseous mixture after an explosion, and when the motor was sparking continuously, a succession of explosions resulted. These followed one another with more or less rapidity, depending upon the character of brush sparking. Under the conditions outlined above it would be merely a matter of time before the protecting plates would become so hot that they would no longer be effective.

Even with the fan removed, a certain amount of fan action was produced by the end conductors of the armature coils. This, however, did not result in a succession of explosions because "afterburning" set in at once; as fast as the gas was drawn in it was burned at the inner edges of the plates. This, as previously suggested, would result disastrously for the windings, but would not necessarily cause a "puncture."

The effect of the fan upon the pressure developed in the casing by explosion is shown very clearly by the tests listed under groups 18, 19, and 20, in which the pressure developed by the initial explosion varied from 24 pounds per square inch at 1,250 revolutions per minute (normal speed) to 34.6 pounds per square inch at 1,790 revolutions per minute.

TESTS OF TYPE E PROTECTIVE DEVICES.

Two hundred and sixty-eight tests were made on the type E devices under twenty-six different conditions. Ten or more tests were made under those conditions that were considered to be most severe, and one or more under all others. Fewer tests were made with back ignition in the "overgas" and "undergas" conditions because back ignition offsets the effect of more or less gas—that is, slow flame propagation.

Although the tests were made with great care, the results of tests made under the same conditions did not always check each other satisfactorily, and in such cases the tests were repeated until at least ten tests were obtained that checked each other within a reasonable percentage of variation. Only the latter tests are reported herein.

In some of the running tests more than one explosion took place within the motor. The total number of explosions within the motor casing was 272.

In Table 4 on page 36 are enumerated the conditions that surrounded each test, the maximum pressure developed within the motor casing, the number of tests made, and the number of "punctures" that took place. For each set of conditions a characteristic pressure card is shown in figures 13 and 14.

DETAILS.

The details of the type E protective devices are clearly shown in Plate VI, *B* and *C*, and figure 12. The devices are described on page 17. Plate IV, *B*, shows how these devices are attached to the motor frame. The safety device on the starting box was practically the same as those on the motor, differing only in details. The gauze sheets were smaller and the spacers were not so thick. The passages between the baffle plates were also smaller.

MOTOR.

The motor to which the type E protective devices were attached was a 250-volt, 4-pole, compound-wound, totally inclosed, direct-current motor designed to operate a coal-cutting machine by gear connection. The motor was rated at 20 horsepower for one hour, with a maximum temperature rise of 75° C.

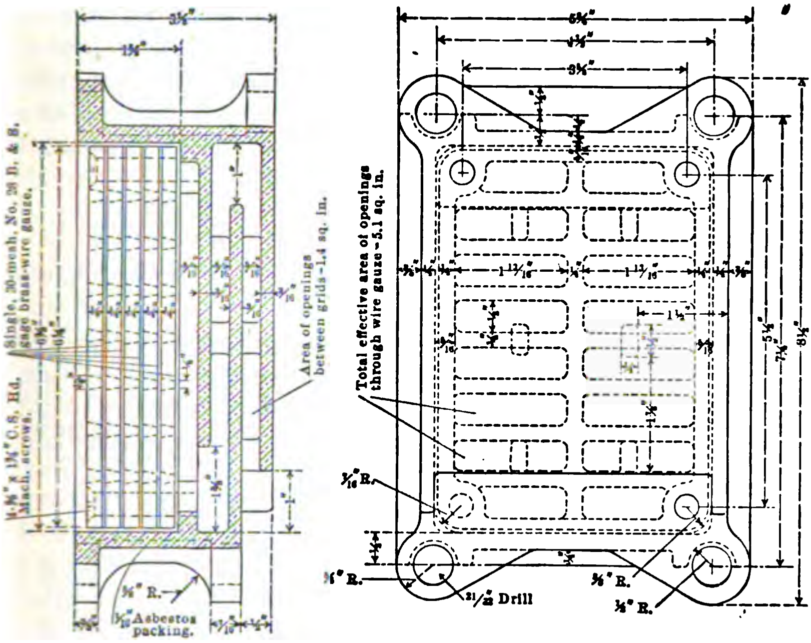
3⅝"
1⅝"
Single, 30-mesh, No. 28 B. & S. gage brass-wire gauze.
4-⅜" x 1¾" C.S. Hd. Mach. screws.
Area of openings between grids-1.4 sq. in.
1"
1⅜"
⅝" R.
1/16" Asbestos packing.
Total effective area of openings through wire gauze-5.1 sq. in.
5⅞"
4⅞"
3⅝"
1 11/16"
1 11/16"
1½"
5¼"
7⅛"
8½"
1¼"
7/16" R.
¾" R.
21/32 Drill
⅝" R.
½" R.

Figure 12.—Dimensions of type E protective device.

The motor leads were brought through a bushed hole in the casing to brass studs set in a hardwood block screwed to the outside of the casing. These studs were provided with lugs and thumbscrews and were protected by a cast-iron cover.

The motor was equipped with a starting box mounted on one side of the motor casing. It was a dial-type rheostat, with the resistance inclosed in a gas-tight nonremovable case, with contacts mounted on a slate slab. Terminals were also provided for a single fuse. The whole was screwed to a cast-steel base, and this in turn was screwed to the motor casing. The leads came through a bushed hole in the motor casing and through an unbushed hole[a] in the base of the starting box. The box had a cast-steel cover, on which was mounted the control lever. The protective device was fastened to this cover. There was no communicating passage between the casing of the starting box and the casing of the motor. The unoccupied space within the motor casing was approximately 0.83 cubic foot, and the unoccupied space in the starting box was approximately 0.185 cubic foot. The combined minimum area of relief openings was 2.8 square inches.

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[a] This hole was plugged by the bureau's engineers before making the tests.

IGNITION POINT.

In the tabulated report "front ignition" refers to ignition from a spark plug fastened at the commutator end of the motor—that is, the end nearest the relief openings. "Back ignition" refers to ignition from a spark plug fastened at the pulley end of the motor—that is, the end farthest away from the relief openings. "Brush ignition" refers to ignition by sparks from the brushes while the motor was running. "Side ignition" refers to ignition within the starting box from a spark plug placed at the side of the box.

FLAMES.

In no tests were any flames observed to issue from the protective devices.

TABLE 4.—*Results of tests of type E protective devices.*

Group No.	Motor condition.	Gas percentage.	Ignition point.	Maximum pressure.	Outside flames.	Typical pressure diagram.		Number of tests made.	Number of "punctures."
						Card No.	Figure No.		
				Pounds per square inch.					
1	At rest....	8.6	Front...	18.0	No....	E-106	13	10	0
2	.....do.....	8.6	Back....	27.4	No....	E-111	14	10	0
3	.....do.....	[a] 8.6	Front...	18.5	No....	E-220	13	10	1
4	.....do.....	8.6	Back....	29.7	No....	E-232	14	10	1
5	.....do.....	9.0	Front...	13.5	No....	E-125	13	10	0
6	.....do.....	9.5	...do.....	10.5	No....	E-154	13	10	0
7	.....do.....	10.0	...do.....	9.0	No....	E-170	13	10	0
8	.....do.....	10.5	...do.....	7.2	No....	E-203	13	10	0
9	.....do.....	11.0	...do.....	4.3	No....	E-211	13	10	0
10	.....do.....	9.0	Back....	23.0	No....	E-128	14	1	0
11	.....do.....	9.5	...do.....	18.5	No....	E-161	14	1	0
12	.....do.....	10.0	...do.....	16.0	No....	E-162	14	1	0
13	.....do.....	10.5	...do.....	11.0	No....	E-196	14	1	0
14	.....do.....	11.0	...do.....	9.2	No....	E-197	14	1	0
15	.....do.....	8.0	Front...	14.8	No....	E-129	13	10	0
16	.....do.....	7.5	...do.....	9.0	No....	E-147	13	10	0
17	.....do.....	7.0	...do.....	8.1	No....	E-183	13	10	0
18	.....do.....	6.5	...do.....	5.5	No....	E-188	13	10	0
19	.....do.....	8.0	Back....	22.0	No....	E-139	14	1	0
20	.....do.....	7.5	...do.....	20.6	No....	E-140	14	1	0
21	.....do.....	7.0	...do.....	12.1	No....	E-184	14	1	0
22	.....do.....	6.5	...do.....	9.7	No....	E-185	14	1	0
23	.....do [b]...	8.6	...do.....	32.7	No....	E-251	14	1	1
24	Running..	8.6	Front...	28.8	No....	E-234	13	4	0
25	.....do.....	8.6	Brush...	20.4	No....	E-239	13	4	0
26	.....do.....	8.6	Back....	47.2	No....	E-256	14	10	0
27	([c])	8.6	Side.....	7.4	No....	E-96-A	14	213	0

[a] In this group of tests finely ground coal dust was sifted into the protective devices before each test.

[b] In this group of tests one of the protective devices was purposely cut out of service, so that all of the products of combustion were discharged through one device.

[c] These tests were made upon the protective device that was attached to the starting box.

DISCUSSION OF TEST RESULTS.

GENERAL REVIEW.

Two hundred and forty-eight tests were made with the motor at rest, with a total of 248 explosions within the motor casing, and a "puncture" occurred only four times. One of these was due to a hole left in the casing by the manufacturers. The other three started from the relief valve, one at 8.6 per cent gas, with dust, front ignition; another at 8.6 per cent gas, without dust, back ignition; and the last at 8.6 per cent gas, without dust, back ignition, and one protective device cut out of service.

Twenty tests were made with the motor running, with a total of 24 [a] explosions within the motor casing. In none of these tests was there a "puncture."

In 213 of the 268 tests the starting box was tested by filling it with the gaseous mixture and igniting the mixture by means of a spark plug. In none of these tests was there a "puncture."

In no test were flames seen to issue from either of the relief valves on the motor itself or on the starting box.

PRESSURE IN THE MOTOR CASING.

The pressure developed within the motor casing varied with the character of the gaseous mixture and the point at which the ignition occurred. The operation of the motor at the time of the ignition also affected the pressure, raising the maximum observed pressure by 60 per cent or more. (Compare group No. 1 and group No. 24; also group No. 2 and group No. 26.)

In the group No. 25 tests, in which the mixture was ignited from a brush spark, ignition took place during the first revolution of the armature and therefore the full effect of running the motor was not obtained, as is attested by the fact that the pressures closely check those obtained with the motor at rest.

The pressure curves (figs. 13 and 14) show very plainly that the conditions that gave maximum pressure coincided with the conditions giving the maximum rate of flame propagation.

The conditions under which the highest pressure was developed were 8.6 per cent gas, back ignition, and the motor running (group No. 26). Under these conditions the maximum heat was developed and discharged from the relief openings in the minimum time. Under these conditions the flames within the motor seem to be most likely to reach the gaseous mixture surrounding it. The maximum pressure measured in this group of tests was 47.2 pounds, which was also the highest pressure measured during the entire investigation.

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[a] In some tests the motor casing was filled and exploded more than once.

PERFORMANCE OF THE DEVICES.

No "punctures" occurred while the motor was being tested with gas alone, excepting in a single test made with one of the protective devices cut out of service. There was one "puncture" out of 10 tests made under group No. 3 conditions. In that test no flames were observed to issue from the protective devices when the gaseous

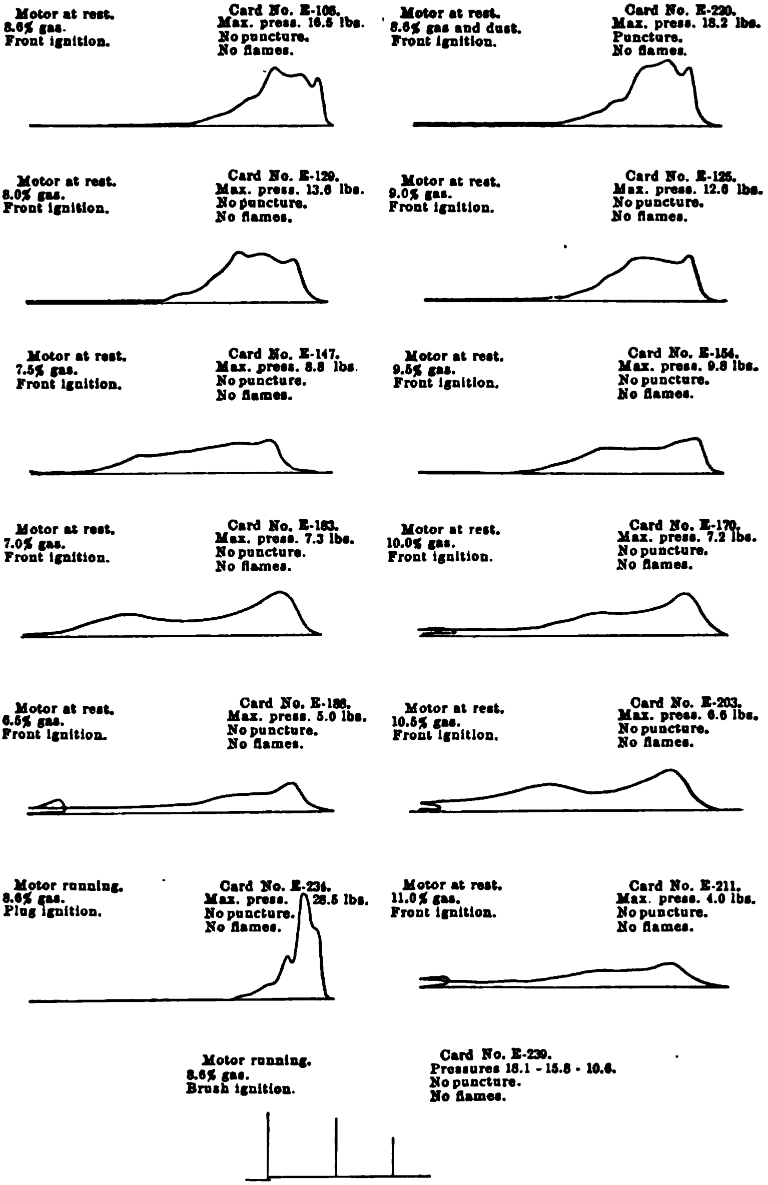

FIGURE 13.—Pressure diagrams for type E protective device.

mixture inside the casing was ignited. The coal dust that had been sifted into the protective devices was driven out in a cloud and the explosion seemed to start from a point within this cloud. This probably indicates that the dust was raised to its ignition temperature before it left the casing of the motor and, upon reaching the outer air, burst into flame and ignited the gaseous mixture sur-

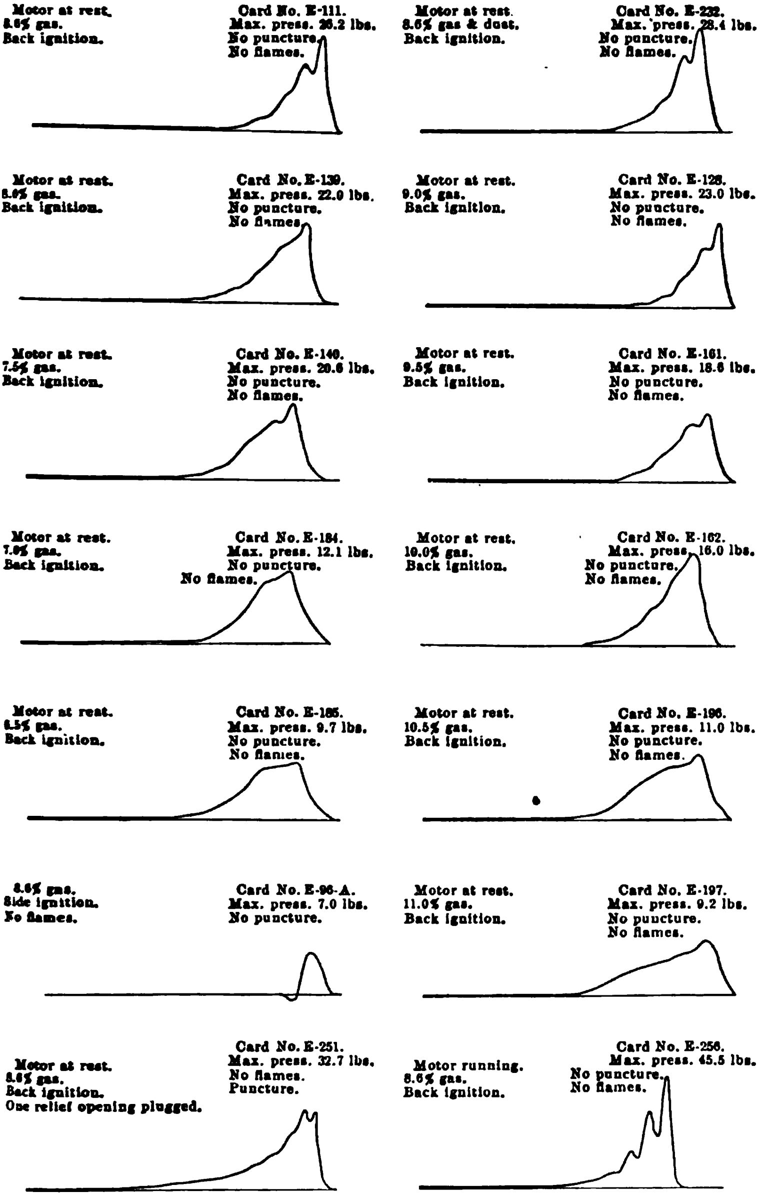

FIGURE 14.—Pressure diagrams for type E protective device.

rounding it. The pressure developed in the motor casing in the test in which there was a "puncture" was less than 40 per cent of the average maximum pressure produced in 10 other tests made with gas alone in which no "puncture" took place.

One "puncture" occurred in 10 tests made under group No. 4 conditions. The circumstances surrounding this "puncture" were practically the same as those surrounding the one just described. No flames were observed to issue from the motor. The dust was blown out in a cloud and ignition took place from the lower edge of the cloud when the latter was about 4 inches out from the relief opening in the protective device. The pressure developed within the motor casing in this test was about 65 per cent of the maximum pressure developed in 10 other tests made with gas alone in which no "puncture" happened.

The single test made under group No. 23 conditions caused all the gases to be discharged through a single protective device. No flames were seen to issue from the protective device. There was a small puff of dust blown out from it, and after an appreciable delay (possibly a second) the gaseous mixture ignited from a point just above the protective device. It is impossible to say that the presence of the small amount of dust was responsible for the explosion, but it appeared to be. The pressure obtained in this test was not excessive, being about 72 per cent of the average maximum pressure obtained in 10 tests of another group in which "puncture" did not occur.

The results obtained indicate that the type E devices give adequate protection when gas alone is used and both devices are in working order. When dust is present, however, the devices do not afford the protection which they are designed to give. The mechanical design of the devices seems to be well suited to the conditions under which they will be expected to operate.

GENERAL DISCUSSION.

REVIEW.

Of the five protective devices submitted, one was rejected without test, one failed completely in test, and each of the others failed under one or more conditions of test. One of the three devices last mentioned discharged flames in almost every test, another discharged flames only when the motor was running, and the third discharged no flames under any condition. The following tabulation compares the more important features of the devices and the results of the tests made upon them.

TABLE 5.—*General comparison of results of tests of five types of protective devices.*

Type.	Character of protection.	S. Unoccupied space in motor casing.	R. Minimum area of relief openings.	$\frac{R}{S}$	Maximum pressure, motor at rest 8.6 per cent gas, front ignition, 20° C., approximate.	Maximum pressure under any condition.	Discharge of flames.	Protection from mechanical injury.	Conditions under which "puncture" took place.
		Cubic feet.	*Square inches.*			*Pounds per square inch.*			
A	Gauze protected by a poppet valve.	1.2	5.22	4.35	20.0	47.0	Yes....	Unsatisfactory.	(a) Valves open, 8.6 per cent gas, front ignition, motor at rest. (b) One valve plugged, 10 per cent gas, front ignition, motor at rest.
B	Unprotected gauze.[a]	......	......	......	......	......	......	......	......
C	Baffle plates	0.68	2.0	2.95	26.0	27.5	Yes....	Good....	8.6 per cent gas, front ignition, motor at rest.
D	Plates......	5.1	48.0	9.4	[b] 11.50	34.6	Sometimes.	Unsatisfactory.	8.6 per cent gas, brush ignition, motor running.
E	Subdivided gauze and baffle plates.	0.83	2.8	3.38	16.5	47.2	No.....	Good....	(a) 8.6 per cent gas and dust, front ignition, motor at rest. (b) 8.6 per cent gas and dust, back ignition, motor at rest.

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[a] Not tested.

[b] The armature fan, even at rest, increased the effective resistance of these protective devices to the passage of gas. With the fan removed, but other conditions the same, the maximum pressure was only 3 pounds per square inch.

A weak point was found in each type of protection. In only 4 tests out of 191 did the type A devices prevent the passage of flames. Such a condition does not appear to be safe and, although few actual "punctures" occurred, the margin of safety seems to be narrow at all times. The successful operation of this type of protection appears to depend upon the dissipation of heat outside of the devices instead of, as was intended, within them. The margin of safety was overstepped when the maximum heat was discharged from the devices at a comparatively low pressure. This was accomplished by exploding the gaseous mixture within the motor casing while the protecting poppet valves were in the open position. Such a condition might exist in practice for the purpose of cooling the motor while in operation.

The type B and the type C devices were not at all suited to the purposes for which they were designed.

The failure of the type D devices was due more to the extremely severe conditions imposed by the motor design than to imperfections in the design of the devices themselves. It is hard to conceive of a device of reasonable size that could absorb the amount of heat produced by the continuous operation of such a motor in a gaseous atmosphere.

The weak point of the type E devices was their tendency to ignite coal dust deposited in the openings of the baffle plates outside the gauzes.

REQUIREMENTS OF EXPLOSION-PROOF PROTECTIVE DEVICES.

Explosion-proof protective devices should be so designed that flames can not be driven through them by an explosion of gas within the casing of the motor to which they are connected. They should also be so designed that coal dust can not enter them or, if allowed to enter, can not be discharged while ignited. Such devices should be very rugged in mechanical design or they should be completely protected from injury. They should also be so constructed and applied to the motor that they can not be detached from it without rendering the motor inoperative.

CASINGS OF EXPLOSION-PROOF MOTORS.

The casings of explosion-proof motors should be designed with the fewest possible number of openings. An ideal casing for this purpose would be one that had no openings whatever except those to which the protective devices were attached. The electrical conductors which enter such casings should be efficiently bushed with hard fiber or some other material that will make a strong and tight joint. If the amount of unoccupied space within the casing is made as small as possible the duty of the protective devices will be reduced to a minimum.

The factory tests to discover unprotected openings in the casings of explosion-proof motors should be as rigid and complete as any tests made upon the protective devices themselves. Several incidents that occurred during this investigation emphasized the importance of making such tests for tightness.

Although the type D motor was carefully examined before the test, an oil drain hole one-fourth inch in diameter escaped notice as it was filled solid with dirt and grease. On the first test this filling blew out and the flames that instantly followed caused an explosion of the gaseous mixture surrounding the motor. That single oversight made the protective devices of no avail.

In the case of the motor that was supplied with the type E devices the preliminary examination revealed two defects that had been overlooked by the manufacturers. These defects were repaired before beginning the tests, but a third defect escaped detection and later caused an explosion.

Obviously the most elaborate protective devices are useless if there are unprotected openings in the motor casing.

The starting boxes of explosion-proof motors should be protected with the same care as the motor casings.

THE DESIGN OF PROTECTIVE DEVICES.

The most satisfactory form of protective device is one that is capable of absorbing a large amount of heat. In order to do this the device must be constructed of a metal that is a good conductor of heat. A considerable amount of metal should be used and it should be so disposed as to offer a large amount of heat-absorbing surface to the flames without being itself raised to an unsafe temperature. The total area of protected openings through the wall of the motor casing should be as large as is consistent mechanically. There are two reasons for this arrangement. First, it permits the use of more heat-absorbing material, and, second, it decreases the maximum pressure developed. The lower the pressure the lower the temperature of the flame and the less heat is passed through the cooling devices in a given time. With a lower pressure the rate of flame propagation is slower; consequently, heat absorption is facilitated.

Use may be made of the fact that the advancing edge of the explosive wave is the most likely to be chilled because it passes through the coolest metal. If, then, the relatively cool dead gas produced by this means is passed through a comparatively long passage, like that between the baffle plates of the type E devices, subsequent flames will be cloaked with noncombustible gas and can cause no ignition.

Finally, the simpler and more rugged the design of such devices the better are they adapted for practical purposes. The devices should be so mounted as to render impossible the separation of plates or the rupture of gauzes. A splendid place for such devices would be entirely within the motor casing, with vent holes for the escaping gases.

LIST OF PERMISSIBLE EXPLOSION-PROOF MOTORS.

The Bureau of Mines is prepared to make tests of explosion-proof motors for the purpose of establishing a "permissible list" of such machines. Schedule 2 of the bureau describes the conditions under which such tests will be undertaken and states the fees charged for the work. This schedule may be obtained by applying to the Director of the Bureau of Mines, Washington, D. C.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 26. Notes on explosive mine gases and dusts, by R. T. Chamberlin. 67 pp. Reprint of United States Geological Survey Bulletin 383.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigation of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 12. The behavior of nitroglycerin when heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp., 1 pl.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp. 1 pl.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369, revised.

MINERS' CIRCULAR 2. Permissible explosives tested prior to January 1, 1911, and precautions to be taken in their use, by Clarence Hall. 1911. 12 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

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Bulletin 47

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, Director

NOTES ON MINERAL WASTES

BY

CHARLES L. PARSONS

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PREFACE.

By J. A. Holmes.

During the past year, in producing 500,000,000 tons of coal we wasted or left underground, in such condition that it probably will not be recovered in the future, 250,000,000 tons of coal; we turned loose into the atmosphere a quantity of natural gas larger than the total output of artificial gas during the same period in all the towns and cities of the United States; we also wasted or lost in the mining, preparation, and treatment of other important metalliferous and nonmetalliferous minerals from 10 to 50 per cent of the year's production of such minerals. These losses serve to indicate the importance of inquiries and investigations by the Federal Government for the purpose of lessening the waste of essential resources—investigations on the same general lines as those looking to a reduction in the loss of life in the mining operations of the country and the far more extensive investigations looking to the more efficient production and use of agricultural products, both of which are being conducted by the Federal Government.

In a consideration of the possible activities of the individual, the State, and the Federal Government in behalf of a less wasteful use of our mineral resources certain facts and principles should be kept clearly in mind, namely:

That the present generation has the power, and it will exercise the right, to use as much of the country's resources as it actually needs; there can and there will be no such thing as stinting the present generation by bottling up resources for the use of the future.

That the Nation's needs are not likely to be curtailed; these needs will increase with the extent and diversity of the Nation's industries, and they will increase more rapidly than population increases, for the reason that the per capita consumption of mineral products is rapidly increasing; and

That the men of this generation will not mine, extract, or use these resources at continuous financial loss to themselves in order that something may be left for the use of future generations; there can be no such thing as a mineral industry without profits.

Furthermore, it should be clearly understood that the mineral resources of this country have required long ages for their accumulation and that of these resources the Nation has but the one supply. There are no known substitutes available to meet the Nation's further needs when that supply will be exhausted and, to the best of our present knowledge, this one supply must serve as a basis for both the needs of the present and the far greater needs of the future.

In a higher way our mineral resources should be regarded as property to be used and to be held in trust with regard to both the present and the future needs of the country. It should be remembered that neither human labor nor any human agency has contributed to their origin or to their intrinsic value, and that whatever rights the individual may possess have been derived from the General Government and from the State as the original owner. The State does not surrender its right, and should not neglect its duty, to safeguard the welfare of its future citizens by preventing the wasteful use of these resources. Though the individual may claim the right to use the resources in proportion to his needs and the needs of the community, he certainly has no right to waste that which is not needed for present use but is certain to be needed hereafter.

Those in charge of the investigations of the Bureau of Mines recognize the rights and duties of the Federal Government as being limited to the carrying on of inquiries and investigations with a view to determining the nature and extent of this waste of resources, the means by which it may be diminished, and the setting forth of the facts in the case.

The present report embodies the results of certain preliminary inquiries as to the nature and extent of this waste. It will be followed by a more detailed report on the subject as soon as the necessary inquiries and investigations have been conducted and the results put in shape for publication.

In the preliminary work along these lines, the representatives of the bureau have received the cordial cooperation of the engineers and chemists associated with the varied mineral industries of this country and also of the owners and the operators of the mines and the metallurgical plants.

NOTES ON MINERAL WASTES.

By Charles L. Parsons.

INTRODUCTION.

The mineral resources, which by their abundance in favored localities have made our civilization possible, required the ages for their building. Through millions, perhaps hundreds of millions, of years their segregation into workable deposits has been going on. Their genesis may still be under way, but the rate of their formation is now infinitesimal in proportion to the rate at which they are being eroded and scattered over the earth's surface.

NEED OF PREVENTING MINERAL WASTE.

It is practically impossible to estimate the supplies of our chief ores and minerals. A few minerals, like the silicates, are inexhaustible; one or two metals, like aluminum, may become so likewise when processes are devised to utilize material not now available. Many new deposits of all will undoubtedly be found; but the ultimate exhaustion and dissipation of some of our important useful minerals of to-day, from the standpoint of the race and in the light of present knowledge, is in sight. This fact deserves serious consideration. Hence, it is of the utmost importance that these minerals be mined, concentrated, and utilized with all practical economy, and that the metals, after serving their purposes in manufactured articles, be collected for reuse wherever possible. These basic principles have all been expounded by many eminent writers, and are brought together in interesting form in the report of the National Conservation Commission,[a] in a book of lectures by Charles R. Van Hise,[b] and in many individual articles in the public press and in scientific and technical publications.[c]

The mineral resources of the United States are greater than those of any other nation. In 1911 the value of the product of our mines and quarries exceeded $2,000,000,000 in the wealth produced by our people, being surpassed only by the value of the product of the soil. No matter of greater moment concerns us, therefore, than the proper conservation of our mineral resources for the needs of the future. This conservation can be accomplished only by avoiding waste in the mining, manufacture, and use of the mineral products that the legitimate advancement of commerce and industry may require.

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[a] S. Doc. No. 676, 60th Cong., 2d sess.

[b] The conservation of natural resources in the United States, 1910, 413 pp.

[c] Mineral wastes symposium. Jour. Ind. and Eng. Chem., vol. 4, March, 1912.

The purpose of the Bureau of Mines in publishing this report is to call attention to some of the present wastes, in the hope that knowledge of the facts may lead to an increased desire to eradicate the wastes, and to a greater interest in careful, practical, and scientific investigations, through which only can they be overcome. Much has already been done, especially in the metallurgy of iron, lead, copper, and the precious metals, and there is no intention of belittling in any way the really wonderful work of the last half century or of the last decade, but time is sure to show that human accomplishment in economical mineral technology is only in its beginnings.

VARIETY OF WASTES.

Wastes in mineral production and treatment are of many kinds. There are wastes in mining, in concentrating or ore dressing, in smelting or manufacture, in flue dust, and in unrecovered dross and scrap. Inefficient methods are adopted through unnoted or undeveloped opportunity. Losses are caused by the use of material entirely unfitted for the use to which it is put. Air and light and moisture cause rusting and decay. Certain uses, such as that of zinc oxide and lead carbonate for paints or for the filling of rubber for automobile tires, leave no practical chance for recovery. Failure to use resources, the value of which is yet unknown, gives rise to economic inefficiency. All present wastes will be largely prevented in future, as science progresses and investigations multiply.

In the process of mining some of the material is inevitably left in the ground, being of too low grade to work with profit, or being necessary for roof supports in the form of pillars. Many ores, formerly of too low grade to pay for extraction, are now sources of wealth, and care should be taken to leave low-grade deposits in position for future development whenever conditions warrant. Improved methods of mining and timbering often permit the complete removal of pillars, and their replacement with valueless material. New forms of machinery will reduce costs, and entirely feasible precautions will lessen the danger to life and limb.

In ore dressing and ore concentration the losses are often startling, and, in spite of the advances in the last few years, this field offers broad opportunity for the investigator. Present practice should always consider the storage of the material now wasted, in the hope that new knowledge may yet render it profitably available. Numerous instances might be cited in which the tailings from gold mines, the slags from copper smelters, and the dumps from mines and manufactories have become a source of wealth, the wastes of the past being thus converted into the dividends of the present.

The dust from stacks and chimneys of all kinds is often not only a great waste of valuable material, but is one of the great evils of modern civilization. Valuable metalliferous dusts are strewn broadcast from the stacks of our smelters; gases and poisonous solids destroy vegetable and animal life; and masses of black smoke pour from our chimneys and settle in clouds over many of our cities, rendering them exceedingly disagreeable and unsightly. Even with present knowledge, practically all dust nuisances are preventable, and legislation the country over is diminishing the dust output from smelters, from cement plants, and from smoking chimneys, often with the result that the collection of dust incident to smoke prevention becomes a source of profit. Specific instances of the wastes mentioned are cited in subsequent pages.

LOSSES THROUGH INEFFICIENT METHODS OF TREATMENT AND USE.

Losses through inefficient methods are not always realized, sometimes because proper practice has not been developed, but oftener because of ignorance resulting from lack of technical supervision, or because of prejudice against its employment. The increase in efficiency of method will surely be greater in the future than in the past, although no fable is more wonderful than the history of the development of the metallurgy of iron through the introduction of the Bessemer and the open-hearth processes, the recovery from the waste gases of heat for the blast and the driving machinery, the dehydrating of the blast, the nodularizing of the flue dust, and the utilization of the slag. The metallurgy of copper has greatly advanced in recent years, but more efficient methods, yet to be devised, will save fuel and conserve the sulphur as well as valuable accompanying metals that now go off in the slag. The methods for winning zinc, owing to the peculiar reaction of that metal, are little changed in principle from those in vogue when the metal was first commercially obtained.

The application of new scientific principles to simple manufacturing practice often brings about incalculable saving. Hess states[a] that the advent of tungsten-steel tools has saved hundreds of millions of dollars in the United States alone by the increased efficiency of over 400 per cent in metal-cutting lathes, and quotes Mr. Elwood Haynes to the effect that a certain automobile company would be obliged to add $200 to the price of each automobile now manufactured should it have to use the old carbon-steel tools instead of the tungsten-steel tools it now employs. Vanadium and molybdenum have much the same effect on steel as tungsten when used in the proportionate amounts of about 1 of vanadium to 5 of molybdenum to 18 of tungsten. The beneficial effects of these elements should not be accorded to them alone, for each must be accompanied by chromium also to give the resulting ferroalloys the properties that render them valuable.

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[a] Hess, F. L., General condition of tungsten industry. Mineral Resources U. S. for 1910, U. S. Geol. Survey, 1911, p. 13.

Another good example of waste in utilization is the failure to use the latest methods in the hardening and tempering of steel. A certain large manufacturer of steel blades, making at the present time some 300,000 blades a day, has reduced his costs more than half through the services of an expert chemical engineer. He now uses some 3 tons of cold-rolled steel per week. The blades were formerly hardened by using 65 machines which, utilizing gas and blast for the heating process, ran day and night and required 15 men for their control. The company is using six electrically heated furnaces, which, in an 8-hour day, give double the old capacity and require the services of only two operators. For the tempering process the blades, 70 pounds at a time, are dipped into an electrically heated salt bath, and are held for a definite period at a temperature precisely controlled by pyrometers. On the other hand, another of our largest manufacturers of small steel articles is still employing the hand labor of blacksmiths for hardening each article, getting a much more variable result at many times the cost. The company is working up hundreds of thousands of dollars' worth of material each year, believing that its supposedly secret practice is an asset of great value. Examples of this kind of waste could be almost indefinitely multiplied.

The prevention of waste of metals is largely a question of their preservation. Metals like copper, iron, gold, and silver tend to accumulate and add to the world's stock. Zinc and probably some other metals are dissipated each year in quantities almost as great as the amounts produced. Accordingly, any means that tends to prevent the destruction of metals, whether it be use of protective coatings of cement, enamel, or paint, or the addition of some substance that renders the metals comparatively immune, such as the addition of copper to iron, is of the utmost importance in intelligent conservation.

Less than half of the known elements of which the earth is composed are now commercially important, and some of the most abundant are the least used. Many instances are on record of valuable but little-known minerals of the rarer elements being passed over and lost through inability of the ordinary prospector to identify them. Future investigation will certainly develop many important applications for materials now useless, and new exploration will develop resources that are now unsuspected.

The scrap heap is receiving more and more attention every day, and important results in true conservation have already been accomplished through the medium of the junk dealer. Iron by the thousands of tons is collected to be resmelted in the open-hearth furnace. Lead scrap, stereotype metal, babbitt, and solder are remelted and reused; tin from tin scrap and tin dross, and zinc from zinc clippings and zinc dross are recovered. Copper from old wire, from discarded copperware, from brass scrap, from bronze scrap, from copper paint sludge, from the ashes of brass and copper furnaces, from molders' sand, etc., is separated from its accompanying metals and comes once more on the market. Gold, silver, and platinum are collected from jewelers' sweepings and dental waste. All this is the truest conservation, for it tends to keep the world's stock intact. Losses, however, are still incalculable, although often readily preventable through application of known remedies or through a little investigation and intelligent experimentation.

In a consideration of this whole question of waste, one should remember that there are many wastes that are necessary under present economic conditions. In all cases, however, every effort should be made to store up for future use material that may, as human knowledge advances, become valuable. The really important problem before the country is to investigate the extent and nature of these wastes and then to find and apply remedies in a thoroughly businesslike way.

FUEL OR CARBON WASTES AND THEIR REDUCTION.

The wastes of carbon in our modern economy are almost incomprehensible. Only the wastes of what may be termed inorganic carbon can be considered here.

WASTES IN THE MINING AND UTILIZATION OF COAL.

In mining coal in this country probably one-third of the bituminous coal and one-half the anthracite are left in the mine. Better methods of mining have reduced past losses and there is prospect of further immediate improvement. The losses from pillars left to support the roof, and from coal left in beds too thin to be mined profitably are sure to continue, but can be greatly diminished. Fully 80,000,000 tons of anthracite coal is now being left behind in the mines each year, and it is estimated that since coal mining began in this country fully

2,000,000,000 tons of anthracite and 3,000,000,000 tons of bituminous coal have been left in the ground under conditions which make future recovery highly improbable.[a]

After coal is mined, the losses by no means cease, although some of the culm that formerly went to waste by millions of tons is now being briquetted and used. Probably not over 11 per cent of the energy in coal is effectively utilized. The remainder of the energy is lost through the inefficiency of the steam boiler, the steam engine, and the electric dynamo. It is estimated that the boiler scale in locomotives alone in this country means a loss of over 15,000,000 tons of coal annually. It has been shown that one-sixteenth of an inch of scale means a loss of 13 per cent and that one-eighth inch, an amount present in many boilers, means a loss of 25 per cent in boiler efficiency. This boiler scale not only causes a loss of energy, but its presence shortens the life of the boiler itself. Careful study of boiler practice has greatly increased boiler efficiency, but, although 80 per cent efficiency is obtained under careful chemical control in the best experiments, not above 50 per cent is obtained in average practice.

In spite of present conditions, great advancement in the utilization of fuel has been made, and greater advances will follow, although the direct utilization of the full energy of carbon through some chemical process may be the dream of the chemical engineer for decades to come.

One of the efficient methods of conserving our coal supplies is through the utilization of water power. Furthermore, the development of the gas engine, by means of which the energy of fuel can be utilized without the intermediary loss involved in generating steam, is rapid. This development has the distinct advantage that much coal, too poor in carbon content to be economically transported, can be readily burned in gas producers and its energy transmitted to a distance through the gas engine and the dynamo. The covering of pipes with asbestos and magnesia coatings and the scientific control of the combustion of coal under boilers are greatly increasing the amount of energy actually utilized, but the losses of carbon that is still pouring from our chimneys, defacing monuments, buildings, and landscape, are without valid reason.

The entirely needless and seemingly ruthless loss of the energy from carbon in the production of coke must also be mentioned. Parker states[b] that the value of the recoverable contents of the coal made into coke in beehive ovens which was wasted in 1910 would have been between $35,000,000 and $40,000,000. If all the coke made in the United States were produced in retort ovens, these would yield from the carbon now wastefully consumed, no account being taken of by-products, approximately 1,000,000 horsepower.

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[a] Holmes, J. A., Carbon wastes. Jour. Ind. and Eng. Chem., vol. 4, March, 1912, p. 160.

[b] Parker, E. W., The production of coke in 1910. Mineral Resources U. S. for 1910, U. S. Geol. Survey, 1911, p. 263.

POSSIBILITY OF UTILIZING COAL TAR.

The argument formerly made against the use of by-product coke ovens, that the output of tar could not be marketed in this country, no longer holds, for not only is there a ready outlet for the crude tar for use on roads, but indications are not lacking that we shall not always be dependent upon outsiders for needed coal-tar products. Germany already makes over four-fifths of her coke in by-product ovens, whereas five-sixths of the coal we coke has some $40,000,000 of its value dissipated into the atmosphere. This loss might be prevented by the use of modern methods.

Without entering into the details of the wonderful coal-tar industry, which, although probably the greatest example of chemical industrial progress, is only beginning to develop in this country, it is interesting to note the indirect bearing of this industry upon conservation through the synthetic preparation of alizarin, indigo, and other colors that were formerly produced from plants grown on land now devoted to other purposes. It has been stated that the synthetic indigo now prepared from coal tar is equivalent in amount to that which would be produced by over 300,000 acres of indigo plants. Furthermore, development of one industry like this always has a decided influence upon another. When the cyanide process for the extraction of gold was first proposed, potassium cyanide cost over $1 per pound. By the untilization of waste products and the perfection of methods, the price of cyanide, now chiefly used in the form of sodium cyanide, has been reduced in the chief producing countries to something like 15 cents per pound, and since a saving of 1 cent per pound of cyanide means a saving of something like $150,000 annually to the gold industry, the cheapening of this product alone means a saving to the world of some $12,000,000 a year.

WASTES IN THE PETROLEUM AND NATURAL-GAS INDUSTRIES.

The 29,000,000 metric tons of petroleum that the United States now produces is for the main part utilized. It is not always used economically, and undoubtedly large losses in lubrication might be avoided. Few people realize the immense amount of lubricating oil used, and there is probably no substance on the market more subject to the abuse of brand. For a consumer to pay more than 50 per cent of the selling price for the name on the container is not at all uncommon, and as regards the high-priced lubricants the same oil can frequently be bought on specification for one-third the price that would be paid for it under some special copyrighted name. This is an economic but not a material waste.

Formerly kerosene was the chief product sought in the distillation of petroleum, and immense quantities of the lighter and heavier fractions were thrown away. With the introduction of the electric light, of the automobile, and of the proper understanding of lubrication, almost the total output of petroleum is now utilized as gas, gasoline, naphtha, benzine, kerosene, lubricating oil, asphaltic road material, and carbon for electrical purposes. Indeed, kerosene has almost become a secondary product, and within the last few years the demand for gasoline has been so great that petroleum companies are anxious to increase the output of that fraction. Not only are investigations under way to convert the heavier products into gasoline by chemical or thermal methods, but the gases from petroleum wells and from natural-gas wells are being subjected to cold and pressure, and a light, easily volatile liquid product is being condensed therefrom, which can be used in gas engines. From some gas wells 2 to 6 gallons of liquid products may be obtained from each 1,000 cubic feet of gas. The gas itself is rendered better for illuminating purposes or for gas-engine combustion, though, of course, its volume is considerably decreased. Many thousand gallons of this kind of gasoline is now produced daily.

The wastes of carbon through the escape of natural gas into the atmosphere are, and always have been, little less than criminal in every new gas or oil field. In most of the old fields these losses have been controlled, and the gas is held stored in its natural reservoir, sometimes under tremendous pressure, until used. Formerly this pressure was utilized at some wells to run engines, the gas itself passing off into the atmosphere, but this waste has been stopped by legislation in most States. In a few cases, in which reduced pressure is desired before running gas into mains for distribution, the high pressure is still reduced through the medium of engines, thus conserving both energy and gas. Although in the more recently developed fields there are still intolerable wastes, it is pleasing to note[a] that careful study and perfection of method are leading to a rapid decrease. Many million gallons of the lighter petroleum products, lying between true gasoline and natural gas, is annually lost by evaporation from the open mouths of petroleum wells and from open storage tanks.

In connection with the utilization of petroleum and natural gas, two problems of importance need solution and will in time be solved. First, a gas engine that will use crude petroleum efficiently will conserve to a large extent the energy that is now wasted in passing through the medium of steam, and will, accordingly, greatly enlarge the area within which ships may travel on a limited fuel-carrying capacity, as well as greatly increase the power produced per fuel unit in all power plants using liquid fuels of this class. Second, there is a rapidly growing demand for hydrogen, both for reducing oils and fats to products of lower melting point and for the development of other processes, which, in part at least, like the proposed contact process for ammonia production, are dependent upon cheap hydrogen for successful exploitation. From petroleum products, as well as from natural gas, hydrogen can be produced and carbon, perhaps as lampblack, be simultaneously obtained.

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[a] Day, D. T., and Hill, B., The production of natural gas in 1910. Mineral Resources U. S. for 1910. U. S. Geol. Survey, 1911, pp. 299–326.

The present process of manufacturing lampblack from natural gas is very inefficient. Not only is the heat of combustion of the hydrogen entirely lost, but a considerable portion of the lampblack actually freed and not consumed is wasted. The recent improvement in methods of dust recovery should make the conservation of this loss an easy matter. B. B. Butler states [a] that in a large West Virginia plant at least 25 per cent, and probably 33⅓ per cent, of the gas burned for lampblack is wasted in the form of a dense cloud of black dust mechanically carried with the draft.

Uses are being sought also for the large quantities of the so-called solar oils of the Texas petroleums, which seem to be too good to be used for fuel but are not light enough to be distilled for kerosene.

ADVANCES IN THE METALLURGY OF IRON.

The metallurgy of iron has reached a perfection beyond that of any other metal, and wastes have been eliminated to an extent that serves as some indication of what perhaps may be done in other industries when the same amount of intelligent investigation has been applied to their development. From the mine up every possible waste has been closely watched and most of the wastes have been eliminated. The poorer ores are being reserved in a condition available for future use; the methods of the blast furnace, the steel mill, and the foundry have been rapidly attaining high efficiency; most of the waste gases and the flue dust are being utilized; and the slag is being converted into Portland cement at the rate of nearly 8,000,000 barrels a year. This advance by no means proves that the end is reached, and, indeed, the outlook for special ferrous alloys, such as those already mentioned and many more as yet undiscovered, is as wide as the future. Moreover, there are millions of tons of titaniferous iron ores not now available that are certain to be utilized by processes now unknown.

THE EXTRACTION AND UTILIZATION OF COPPER.

Next to the metallurgy of iron, that of copper has probably been the most developed. Losses in mining and ore dressing are large, however, particularly in the concentration of some of the low-grade ores, in which heavy metal or sulphide minerals are mixed with the lighter oxides or carbonates. In dressing these ores, a loss of 30 to 40 per cent in the tailings is by no means rare. There have been great advances in smelting, however, as well as in the utilization of ores of such low grade that their successful exploitation 10 years ago would have been deemed impossible.

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[a] Butler, B. B., Min. World, vol. 35, Oct. 28, 1911, p. 864; Chem. Abs., vol. 6, 1912, p. 800.

The fact is that some bodies of low-grade ores are proving more profitable to work, because of their size, than some high-grade ore-bodies, and hence the cost of the metal has not increased, as might have been anticipated. Indeed, although our production of copper has increased about 1,000 per cent in the last 25 years, the annual output as well as the annual consumption is still increasing, and prices are lower than they were a few years ago, owing to the greater efficiency of method and the utilization of deposits formerly supposed to be worthless. Immense deposits of ore yielding less than 2 per cent of metal are worked with steam shovels, and the ore is concentrated in mills capable of handling some 20,000 tons per day, and is smelted by methods far more efficient than formerly. Furthermore, it is bessemerized in basic-lined converters capable of handling three times the charge of the old acid form, and having a life many hundred per cent greater. These low-grade deposits, instead of causing an increase in the price of copper, are really forcing some of the high-grade mines to struggle for a continued existence. In spite of all this, it is doubtful whether there is any branch of metallurgy that would respond more quickly to scientific research by well-trained men, if they were not forced always to keep the immediate output in mind, than the metallurgy of copper. Just what lines these advances will follow, it is impossible to predict, but almost inestimable losses of sulphur, arsenic, bismuth, etc., are now taking place in the flue dusts and flue gases, and there can be little doubt that these will be controlled in time. Electrolytic or electrothermal methods, accompanied by leaching, may yet produce the copper more cheaply direct from the ores, and more efficient concentration is certain to come.

RECOVERY OF COPPER FROM SCRAP.

Here, the junk dealer is performing an especially important service, for all scrap containing copper is eagerly sought, and the copper removed. Copper-wire scrap by the thousands of tons is annually gathered, the insulation, if present, burned off, and the whole simply remelted, poled, and cast again into wire, or into bars or ingots for redrawing. Brass, bronze, coppered tin, etc., of unknown composition, when gathered together in endless variety of kind, such as bases of electric lamps, brass and copper turnings and shavings, cartridge shells, broken and battered household goods, old pipe, brass tinsel, molding sand from brass foundries, concentrates of ashes from brass furnaces, copper paint sludge, and flue dust, much of the miscellaneous collection being briquetted, is treated direct in a copper blast furnace. From this furnace is produced an impure alloy containing about 86 per cent copper, which goes to the blister furnace to be cast direct into anodes or is sent to a refining furnace to make casting copper. In the smelting the zinc, iron, nickel, tin, antimony, and lead present are entirely lost, either in the fume or in the slag. Practically all copper-bearing junk is treated in this manner, except for what medium-grade material is added directly to the reverberatories. When trimmings or turnings of some special alloy of known composition are obtained in sufficient quantity, they are usually remelted direct with more fresh material of the same composition, generally for reuse in the same works, or the same class of works, from which they were derived, although this kind of material, in a sense, does not deserve to be classed as junk at all. However, a single smelter near New York recovers as much as 10,000,000 pounds of copper a year from true junk, and many other works throughout the country are resmelting such material.

PRODUCTION OF NICKEL AND COBALT.

Nearly all of the nickel used in the United States is imported from Canada. Large quantities of this metal are, however, known to exist in Idaho, and an immense deposit [a] of a low-grade, hydrous nickel-magnesium silicate occurs at Webster, N. C. The latter deposit contains millions of tons, but owing to its low-grade character no method of economically working the material has yet been found. Of course, the same statement was true of similar ores of copper ten years ago, but this nickel ore has the disadvantage that it is not amenable to ordinary methods of gravity concentration. A few tons of nickel is made from the nickel that accumulates in the electrolyte of copper refineries and one smelter in the Northwest is producing some metal. The larger part of the output is understood to be now used in the form of monel metal, an alloy obtained direct from the ore and in which the expense of first separating pure nickel has consequently been avoided. The use of nickel as a catalytic agent to bring about the absorption of hydrogen by certain oils and fats has recently become important, as valuable commercial products are obtained.

The production of cobalt in the United States is a problem connected almost solely with imported Canadian silver ores from the famous Cobalt, Ontario, district. Cobalt oxide has recently much decreased small iron articles and wire with this iron-zinc alloy has a promising field of usefulness.

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[a] Morrison, W. L., Electric-furnace treatment of nickel ore and the development of a commercial process. Trans. Amer. Elec. Chem. Soc., vol. 20, 1911, p. 316.

Some 40,000,000 pounds of zinc oxide is used annually for a filling in automobile tires, and the remainder of the 60,000 tons now produced annually in the United States is used chiefly in paint. In neither instance is the zinc ever recovered.

WASTES IN BRASS MANUFACTURE.

W. H. Bassett[a] has brought out very clearly the great losses of zinc in modern methods of brass manufacture and states that there is 6 per cent of the zinc present lost in making brass castings and probably 10 per cent loss in making wrought brass. Brass furnaces are capable of great improvement, and it is certain that special forms of furnaces using an open blast cause even greater losses than those above mentioned. A careful study of the furnaces melting brass would almost certainly produce beneficial results. The problem is one of the greatest importance in the conservation of waste in alloy manufacture.

At atmospheric pressure pure zinc boils at about 930° F. When zinc is diluted with copper the boiling temperature of the mixture is, however, much higher. In present practice these zinc alloys are melted, either in crucibles with a simple charcoal cover or in open gas-fired furnaces. In the practically open containers of this kind it is not at all surprising that zinc sublimes from brass or other alloys at temperatures even below its melting point, for the vapor pressure of the zinc has no chance of ever reaching atmospheric pressure, since the vapor is continually carried away by the air currents.

The solution of the problem of eliminating this loss is undoubtedly the use of a closed furnace of some kind; an electric furnace properly constructed to overcome other difficulties, of which there are many, would be ideal. The cost of current might be high, but other advantages, such as large units, easy stirring, low labor cost, nonintermittent firing, and saving of zinc, would probably more than compensate. Every theoretical consideration indicates that there should be a great field for the electric furnace in connection with zinc alloys, and that with its use the present great losses of zinc in alloys would be largely overcome. Catching the zinc oxide from the present form of furnace is easy with modern methods of dust catching; but if coal or coke be used the oxide caught is so mixed with foreign material as to be worthless, except possibly for making zinc chloride for impregnating timber. By substituting petroleum or producer gas in firing, the recovery of the zinc oxide would probably even now pay commercially, but the problem of preventing its formation would seem to be even simpler.

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[a] Mineral wastes symposium. Jour. Ind. and Eng. Chem., vol. 4, 1912, p. 164.

In brass manufacture large quantities of clean scrap of known composition are directly remelted, with the addition of spelter to make up for that which is carried off in the flues. It is estimated that 7,500 pounds of zinc are passing into the atmosphere daily in the form of zinc oxide from the stacks of the brass-casting shops in Waterbury, Conn., alone. Dirty scrap, as well as the concentrates from the ashes of crucible furnaces and from molders' sand, are generally worked up as previously described in the recovery of copper, the zinc contained, roughly estimated as over 2,000,000 pounds per year, being a total loss.

As already indicated, there is no broader field for research or one that offers more to the cause of conservation than zinc losses and their prevention.

CONSERVATION OF GOLD AND SILVER.

The high value of gold and silver has not only been a natural incentive for the conservation of those metals, but has made profitable the recovery of all waste in their production. The cyanide process for dissolving gold gives a very high recovery and has largely superseded chlorination. Wherever lead or copper smelters are available the ores, unless of unusual richness, are simply smelted with the lead or copper ores. The silver and the gold are recovered from the lead by the Parkes process and from the copper through the residues from the electrolytic refining. The doré obtained is almost always refined electrolytically with some recovery of platinum and palladium from the electrolyte.

Gold and silver are being gradually accumulated in the world's stock. Scrap metal is gathered from the large manufacturing firms, and even the sweepings from small jewlers' shops are saved. Sweepings are also collected from dental houses. These so-called sweepings are generally hand sorted, platinum residues going to platinum refiners. The more valuable portion of the silver and gold scrap is melted with copper into bars and sold to the refiners on an assay basis. The bars are then cast into small anodes and the copper is separated electrolytically, the gold and silver going into the sludge to be treated in the regular manner. The copper anodes produced are always remelted and passed to the regular copper refinery, this double refining being commercially profitable on account of the quick recovery of the major part of the gold and silver, and the consequent lessening of interest charges. The poorer quality of scrap is broken up in ball mills to a fine powder so as to be readily sampled, and this class of "sweeps" is briquetted with a lime binder and is used as a part of the charge of a lead or a copper blast or shaft furnace.

NEED OF PLATINUM AND PALLADIUM.

Every effort should be made to search systematically for platinum in the placer and ore deposits of the western States, for the demand has greatly increased. Owing to the popular craze for platinum in jewelry and owing to its use in dentistry the price of this metal, which is now absolutely essential to scientific research, has trebled in recent years. One producing company is now obtaining each month about 150 ounces of mixed platinum palladium, which contains about 120 ounces of palladium. The metal is being saved in the refining plants, although as a rule smelters do not as yet allow anything for it in ores.

Platinum is being sought more and more in the West. The Rambler mine, which was supposed to be worked out, has seemingly struck ore again. This ore formerly carried about $14 worth of platinum per ton.

Palladium is used in jewelry and also in making the dividing scales of delicate astronomical instruments. Its price per ounce is about the same as that of platinum, but palladium has the advantage of lower specific gravity.

Platinum is being conserved by the substitution of a wire of nickel-chromium alloy covered with platinum for the entrance wire of electric-lamp bulbs. This alloy is also being used for other purposes for which pure platinum was formerly used. Also it is probable that the alloy developed by S. W. Parr,[a] which is extremely resistant both to heat and acids, will find application in calorimeter bombs and for other purposes for which platinum is now required.

MAINTAINING THE SUPPLY OF TIN.

Although this country leads the world in the production of many of the important metals, an output of tin has been singularly lacking. There is some indication that Alaskan deposits may add to our resources of this metal, and it is possible that a considerable output may yet come from Texas and South Dakota mines.

Tin is a comparatively high-priced metal, and a domestic source of supply is greatly needed. In spite of the detinning recovery processes a large quantity of the tin produced each year is lost. However, great advances have already been made in recovering used tin, and the tin drosses of our tin-plate manufacturers are now largely resmelted both in reverberatory and in special electric furnaces. Indeed, waste heaps of dross from former years have been carefully reworked. One company that has buildings standing on old accumulations of dross has seriously considered tearing down the buildings in order to recover the tin in the former waste.

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[a] Mineral wastes symposium. Jour. Ind. and Eng. Chem., vol. 4, 1912, p. 169.

Four detinning processes are at present in use in America. All work over tin scrap and clippings incident to the manufacture of tinware and none, in spite of a popular belief, at the present time recovers any large amount of metal from old tin cans. Tin scrap to the amount of about 150 tons per day is treated in this country with a recovery of 1.5 to 1.75 per cent of tin. One company dissolves the tin from the scrap with stannic chloride and another with sodium hydroxide, but both recover the metallic tin electrolytically. A third company produces stannic chloride by dissolving the tin with liquid chlorine, and a fourth produces tin oxide, possibly by electrolyzing the metal in a bath containing sodium nitrate.

The obtaining of tin from tin cans is so complicated by the expense of gathering the cans, dissolving off the solder, and of removing the detinning agent from the irregularly crushed metal that it has seemingly not proved a commercial success. However, large quantities of tin cans are collected from city dumps and are remelted to an impure form of iron, generally used for sash weights in so-called sash-weight factories, which use not only scrap tin but also scrap galvanized iron without attempting to remove the tin or zinc, a process that would be necessary if this iron were to be used in the open hearth. However, most of the zinc or tin present passes off by the stack or in the slag. There appears to be about 2 per cent of tin on fresh tin scrap, but only about an average of 1.25 per cent on old tin cans.

THE WASTE OF CADMIUM.

As western spelter contains an average of over 0.3 of 1 per cent of cadmium and as there was 230,169 tons of this spelter produced in 1910[a] there was, accordingly, over 700 tons of cadmium sold as an impurity in zinc in that year. Cadmium is easily distilled fractionally from zinc, in which it is an undesirable impurity, especially if the zinc is to be used for the manufacture of lithophone. Flue dust from coal-fired brass furnaces carries about 1.25 to 1.5 per cent of cadmium, which is about 5.5 per cent of the zinc actually present. On this basis there is some 400 pounds of cadmium lost each day from the flues of the brass works of Waterbury, Conn.

The United States imported 4,000 pounds of cadmium in 1910 and produced about 5,300 pounds, the price varying from 60 to 70 cents per pound. It is reported that furnaces capable of producing 1,000 pounds a month are about ready to operate. New uses for cadmium are desired. At present its chief use is in glass manufacture and as a constituent of easily fusible alloys. It has also found application as a constituent of a silver-cadmium plating alloy. If cheaper, it could be used extensively as a yellow pigment. Cadmium sulphide is said to have been used formerly instead of lead chromate as a yellow paint for horse cars, its use being necessary because the cars were kept in horse barns, where hydrogen sulphide blackened the chromate. Now that trolley cars have replaced horse cars, the cheaper lead chromate can be used to paint cars yellow.

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[a] Siebenthal, C. E., Mineral Resources U. S. for 1910, U. S. Geol. Survey, 1911, p. 264.

THE LOSSES OF LEAD.

Van Hise states that the losses of lead are 15 to 20 per cent in mining, 15 per cent in concentration, and 15 to 20 per cent in smelting. A large part of the lead mined is applied to uses that prevent its recovery; namely, as a pigment and as a filler for rubber. Perhaps 30,000,000 pounds of lead carbonate was used as a filling for rubber goods during the past year.

NEED OF CHEAPER METHODS OF OBTAINING ALUMINUM.

Twenty years ago aluminum sold for $5 a pound; to-day it can be bought for less than 20 cents and still is obtained from only one ore, bauxite, the deposits of which, although far from inexhaustible, are much more extensive than generally supposed. Though bauxite is still cheap [a] and is reasonably available, there is great need of a method that will cheaply convert it or some other material into pure aluminum oxide, since pure alumina, free from iron and silica and ready for the electrolyte, now sells for about $60 per ton. Bauxite has many other uses and is needed for the manufacture of alum and aluminum salts in the chemical industries, also for making refractory and abrasive materials.

In the manufacture of aluminum one of the chief items of expense is the preparation, from bauxite, of alumina free from iron and silica. Extensive deposits of true halloysite on the eastern slope of Taylor's Mountain, 5 miles north of Gore, Ga., are now being exploited; large deposits of the mineral are also known to exist in Indiana.[b] Halloysite contains 30 to 35 per cent of alumina that is claimed to be soluble in dilute sulphuric acid and to form a clear white alum cake almost entirely free from both iron and silica. There seems to be no good reason when these facts become more generally known why methods can not be devised to obtain pure alumina cheaply from this source.

Any method for producing aluminum cheaply from clay would be of inestimable advantage. Several new patents have recently been issued and experiments are under way in this country which give some promise of success. The possibility of concentrating bauxite when mixed with clay has been little studied. There are known to be considerable deposits in central Georgia that may pay for further exploitation. The consumption of aluminum has grown from 83 pounds in 1883 to 47,734,000 in 1910.[a] Both the metal and its alloys are finding new applications daily.

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[a] W. C. Phalen presents figures showing that the production of bauxite in the United States in 1910 amounted to 143,932 tons valued at $716,258, or $4.81 a ton. (Mineral Resources U. S. for 1910, U. S. Geol. Survey, 1911, p. 713.)

[b] Indiana Dept. Geol. and Nat. Res., 29th Ann. Rept., 1904, pp. 54–58 and 388–393.

ANTIMONY AND ITS USES.

Some losses of antimony are taking place from the flues of our smelters, but the amount is not comparable with the arsenic given off. Antimony lithophones are stated to have been successful in Germany. The oxide itself may be used as a white paint, and sodium metantimonate is a valuable constituent of enamels. It is an important constituent of bath-tub enamels, replacing to a considerable extent the more costly tin oxide. Its use in enamels placed on cooking utensils is forbidden abroad, but so far these enamels have not been widely prohibited in the United States. Antimony is an essential constituent of some of the most important alloys, especially type and stereotype metal and the bearing metals. Type metal for the main part derives its antimony from antimonial lead. Babbitt metal is supposed to be made by mixing pure antimony, because all antimonial lead contains deleterious arsenic, but doubtless large quantities of the antimonial lead are frequently used. An alloy of pure antimony with lead is now being used in the form of pipe and tubing as a conduit for carrying telephone and telegraph wires. This alloy may entirely displace the old lead-tin compound. The United States produces little pure antimony, although the Arkansas mines are again being opened.

THE PRODUCTION OF BISMUTH.

The uses of bismuth are growing and if the metal could be obtained more cheaply, these uses would be greatly increased. Inquiries have recently been made for alloys of bismuth and lead which were wanted by the ton if they could be had at a low enough price. Large quantities of bismuth are being wasted in this country. Probably 4,000 pounds per day is going out of the stacks of the smelters in the Western States, and it is understood that one or two smelting companies are already installing processes for obtaining the metal and placing greater amounts of it on the American market. In 1911 nearly three-fourths of the domestic consumption was imported. Bismuth is not a desirable constituent in lead, and it must be separated from lead that is to be used for many purposes. The bismuth now produced in this country is obtained as a by-product in refining lead. The lead is melted and allowed to crystallize, and the mother liquors become richer and richer in bismuth. Finally these mother liquors are refined electrolytically and the bismuth is recovered from the slimes.

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[a] Phalen, W. C., Mineral Resources U. S. for 1910, U. S. Geol. Survey, 1911, p. 717.

NEW USES FOR TUNGSTEN, VANADIUM, MOLYBDENUM, AND TITANIUM.

Among the comparatively rare elements that are becoming more and more prominent in industry may be mentioned tungsten, the ores of which to the extent of some 6,000 tons per annum are now mined and treated for use chiefly in the production of tungsten-chrome steel and the filaments of electric lamps. A moderate quantity of the metal is now being obtained from Colorado ores.

There seem to be opportunities in the metallurgy of pure tungsten which have not yet been completely developed. A few years ago tungsten was regarded as unobtainable except as a brittle metal, but by one of the most remarkable of the many investigations dealing with the application of science to industry the pure metal, although melting at a temperature above 3,100° C., is now being drawn into wire and molded into forms. More than a million feet a day of such wire is being drawn in this country for electric lamps, and hammered pieces of the metal are being utilized for the targets of unusually effective Crookes tubes for production of the X-ray. Tungsten ribbon is used in electric resistance furnaces in an atmosphere of hydrogen to produce temperatures heretofore impossible, except in the electric arc. The development of other uses for the metal is certain.

Vanadium is employed in the preparation of vanadium steel, which is supposed to have special toughness and resistance to shock. This element when added with chromium to steel can replace tungsten for the manufacture of tools capable of cutting when hot. Much less vanadium is required than tungsten, but because of price there is no present prospect of vanadium replacing tungsten for this use.

Vanadium ores occur in some quantity in Colorado and other parts of the West, but the known deposits there probably can not withstand strong competition, if such should develop, from the ores obtained in Peru, which are of very much higher grade and are found in that country in seemingly great quantities in one particular deposit.

The preparation of ferrovanadium is comparatively simple and the methods used are essentially the same as one used in the preparation of ferrotungsten. Although little information is at hand in regard to the methods for the preparation of ferrovanadium, the separation of the metal from the ores probably comprises treatment with sulphuric acid, evaporation of the solution, ignition, and reduction of the concentrate with the mixture of iron oxide and aluminum known as thermite.

In Maine and in the West occur large molybdenite deposits which have been useless for the reason that methods of separating this mineral from the gangue have not been successful until recently. Molybdenite in this country generally occurs disseminated in small particles through a large amount of siliceous material, from which it must be separated before chemical treatment. Accordingly, the only molybdenum used has been derived from imported molybdenite, chiefly from Australia and Ceylon, and more recently from Canada, in which countries masses of some size can be picked from the gangue by hand. Manufacturers have been willing to pay as high as $700 per ton for small lots of good hand-sorted molybdenite, but the market has not been extensive. Two new methods, one a flotation method and the other an electrostatic method, are now advocated for separation of the material, giving grounds for hope that American deposits of this mineral may soon be utilized.

Molybdenum has almost exactly the same effect on steel as has tungsten, and 5 parts by weight of molybdenum can replace approximately 18 parts of tungsten, but it is not used extensively in steel because tungsten is cheaper, and especially because molybdenum has the disadvantage of volatilizing out of steel rather easily even under the blacksmith's hammer. There seems to be little prospect that it will replace tungsten in ferroalloys, but there is a considerable demand for its salts in chemical laboratories and in certain blue pigments used in the manufacture of porcelain and for dyeing silks and woolens. It is of special value in steel used in the manufacture of permanent magnets. It can be obtained in the form of ribbon for electrical heating purposes. On account of its ductility and high melting point it is used as a support for the tungsten wire in incandescent electric lamps.

There is a growing demand for the mineral rutile, from which titanium is most readily prepared. The uses of this metal have greatly increased in the last few years. In its alloy with iron it is now used in practically all rails made of Bessemer steel, its function seeming to be to deoxidize and to denitrogenize the ingot so that the rails are sounder and stronger. There is also a considerable demand for the preparation of titanium carbide to be used in arc lamps of exceptionally high efficiency.

Immense quantities of titanium occur in this country in the form of titaniferous magnetites, many deposits of which are now next to useless as iron ores on account of the titanium content. Some of these ores may perhaps be used in the manufacture of ferroalloys, but they are not used as yet for the making of the pure metal. Titanium is so widely distributed that it can be found in most rocks, although only in traces in some. In practically all secondary kaolins the element is a real nuisance on account of the yellow color it gives to wares.

POSSIBLE SOURCES OF RADIUM.

Radium is of value in the treatment of certain diseases and a larger supply is greatly desired by the medical fraternity. Foreign governments have undertaken its production, but nothing has been done in the United States, although two companies are now experimenting on its production. Large deposits of carnotite, a low-grade uranium ore, occur in Colorado, others have recently been found in Oregon, and there is every reason to suppose that exploitation of two mines known to contain pitchblende would produce an output of this wonderful but very rare substance. Investigations of methods of mining and concentrating the ore and of recovering the substance might well be undertaken with the hope of improving these methods and of increasing the stock of this truly marvelous substance. The price of radium is now about $80 per milligram of 2,000,000 power. The production in 1910 was 1.92 grams, which sold for about $150,000.[a]

NEED OF NEW ALLOYS.

No field for investigation offers more promising returns at the present time than that including a continued study of the properties of various known alloys and a search for new alloys for specific purposes. This fact has been clearly brought out in articles by W. H. Bassett,[b] by W. R. Whitney,[c] and by numerous publications of the American Society of Mechanical Engineers, the American Institute of Metals, the Institute of Metals of Great Britain, and the National Physical Laboratory of England. Wonderful results with reference to the ferrous alloys have already been attained, but work on the nonferrous alloys has not received so much scientific attention. The effect of comparatively few elements on brass, for instance, is known except of those, such as iron, which have a strikingly deleterious effect.

Alloy manufacturers have found out through sad experience some of the things that they must keep out of their alloys, but there is every reason to believe that the addition of other substances, also in small proportions, may be found to be as desirable in the making of alloys as in the manufacture of steel. If, for example, there could be found some substance that added to brass would greatly retard the growth of its crystals so that the cast metal would have a finely crystalline rather than a coarsely crystalline structure, the tensile strength of brass could certainly be increased at least 50 per cent. That a small proportion of copper added to iron almost eliminates the corrosive effect of weak acids or acid salts on the iron was discovered a short time ago, but the discovery is already of far-reaching importance.

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[a] Met. and Chem. Eng., vol. 9, April, 1911, p. 201.

[b] Need of special alloys for special purposes. Jour. Ind. and Eng. Chem., vol. 4, 1912, p. 167.

[c] Alloys. Chem. Eng., vol. 14, October, 1911, p. 397.

The element boron has only recently become available through the researches of Weintraub,[a] who has shown that the addition of a small proportion greatly increases the ease and perfection with which copper castings can be made. Such castings can now be obtained having a conductivity formerly impossible. Other instances might be given, but certainly in this field almost nothing is known compared with the results that intelligent research is certain to bring forth.

THE SEARCH FOR POTASH.

At present the United States is more dependent upon a foreign country for potash salts than for any other one commodity except coal-tar colors, which, like potash, come almost solely from Germany. The public press and the technical journals for some months past have contained article after article upon the subject.[b]

In combined but unfortunately in relatively insoluble form there are unlimited supplies of potash in this country. Because no methods are known for economically obtaining the potash we are obliged to import from Germany about $15,000,000 worth each year. Potash is absolutely essential, and unless methods can be found for obtaining it from domestic supplies, we shall be obliged to continue to purchase it from Germany at a price at least 400 per cent more than the cost of delivery in New York.

The feldspars in the granite, as well as in the dikes or veins of pegmatite in this country, contain billions of tons of potash; the rocks of the leucite hills of Wyoming carry over 8 per cent; the alunite veins of the West contain some 10 per cent; and the giant kelps on the seacoast of California annually gather within their structure an amount of the valuable chloride that from analyses and estimates seems to exceed 8,000,000 tons. Yet in spite of the immense quantities of potash within the United States no method for producing the substance in quantity is yet developed.

The soluble potash of the German deposits, which are mainly in the region around Stassfurt, was gathered together by nature in enormous quantity in the bed of an ancient inland sea from which the supplies are now drawn. The material is in soluble form, and needs simply to be mined, being sold either without other treatment than simple grinding or after having been concentrated by evaporation and fractional crystallization. No like deposits are known in this country, although if a large number of widely separated bore holes could be sunk in selected areas it is by no means improbable that beds would be found. The ordinary bitterns from our salt wells, although invariably containing potash, carry too small a quantity to pay for evaporation. Chemical methods have been proposed for treating our feldspars, and one or two of these have some prospects of a limited success. Moreover, it is greatly to be hoped that the immense masses of seaweed, referred to as giant kelps, growing upon the Pacific coast may be utilized. Their dried substance carries in potash and iodine, according to D. M. Balch,[a] who first described them, material worth about $20 per ton. Whether this material can be profitably extracted depends solely upon the cost of gathering and drying. The alunite deposits could certainly be worked commercially if they were only nearer the markets for their products, and they may be developed under present conditions. There is also a possibility, which seems well worth thought and experiment, that no little potash may be obtained as a by-product in cement manufacture, as suggested on page 39. Authoritative announcement has been made by the United States Geological Survey of the discovery of deposits of potash in the brines of Searles Lake, San Bernardino County, Cal. These deposits are estimated to contain 4,000,000 to 10,000,000 tons of potash. The discovery is of the utmost importance and is probably only a presage of the future. Confident prediction can be made that in time this country will be able to produce its own potash supplies. How soon depends largely on the energy and money expended in the necessary investigations.

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[a] Weintraub, E., Preparation and properties of pure boron. Trans. Am. Elec. Chem. Soc., vol. 16, 1909, pp. 165–184.

[b] Cameron, F. K., Waste and conservation of potash and phosphoric acid. Jour. Ind. and Eng. Chem., vol. 4, 1912, p. 169; Mitchell, G. E., The potash search in America. Rev. of Rev., January, 1912, pp. 73–77; Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah. U. S. Geol. Survey Bull. 511, 1911, 64 pp.

WASTES OF ROCK PHOSPHATE.

The fact that the supplies of high-grade phosphate rock within our borders are sufficient for our needs for many hundreds of years to come is no good reason for the losses that are still taking place in Florida. According to Cameron the tonnage wasted in the Florida pebble field is two or three times the tonnage of rock saved, mainly because of washing away of fine particles by the water used to mine and clean the larger aggregates. In the Tennessee field the wastes appear to be fairly well in hand and reduced as much as could reasonably be expected. Mining has not begun to any extent in the immense fields of Wyoming, Montana, Utah, and Idaho. Exports of this material are falling off owing to competition arising from the unusually rich deposits that have been discovered on Christmas Island in the Pacific.

WASTE AND RECOVERY OF NITROGEN.

Ages ago there were stored up, chiefly through the influence of plant life, immense deposits of nitrogen. Although some of this nitrogen may have been brought into combination by means of electrical discharges through the atmosphere, a highly probable assumption is that the larger portion of it was fixed through the same form of bacterial action that is now known to take place in the tubercles growing upon the roots of the *Leguminosæ*. Certainly it appears to be true that the 500,000,000 tons, more or less, of sodium nitrate that is known to have been deposited in the desert of Atacama, Chile, is probably of organic origin; that is, animal refuse was oxidized and the nitrate was collected under peculiar conditions of high temperature and scanty water supply. Bituminous coal contains 1 to 2 per cent of nitrogen, a small fraction of which can be recovered by proper methods. From these sources, except for the comparatively small amounts that have been conserved by saving animal and plant refuse and returning it to the soil, we have until recently drawn our total supply of nitrogen, that element which is absolutely essential for both plant and animal food. Our explosives, upon which depends our whole mineral industry, have also necessitated a large use of nitrogen obtained from the Chile deposits.

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[a] Jour. Ind. and Eng. Chem., vol. 1, December, 1909, p. 777.

Our wastes of nitrogen, worth in combined form about 15 cents per pound, are almost inconceivable, and no calculation can give us a real idea of what these losses mean. Their immensity has so impressed the human mind that the daily press for years has contained article after article, now known to be needlessly alarming, in regard to the starvation of man through the inability of the earth to support plant life on account of a coming lack of nitrogen. Two million six hundred thousand tons of sodium nitrate is being produced each year in Chile, a rate of production which means that the exhaustion of these deposits is probably less than a century ahead.

WASTE OF THE NITROGEN IN COAL.

Although we produced last year over 406,000,000 tons of bituminous coal, we recovered only $3,800,000 worth of the $160,000,000 worth of recoverable nitrogen contained in the coal. Of course, it is entirely impracticable under present conditions to recover as ammonia all of the nitrogen that might be obtained, but it does seem most regretable that of 63,000,000 tons of coal converted into coke in 1910, containing $22,000,000 worth of recoverable nitrogen, only about one-sixth was treated in ovens or retorts which could make that recovery possible. The rest of the nitrogen in the coal went off as free nitrogen in the air.

Pennock, in an excellent article on "Losses of combined nitrogen,"[a] states that between 1893, when the first by-product coke oven was built in this country, at Syracuse, and 1910, "the coke coked in beehive ovens, where the volatile nitrogen was ruthlessly wasted in fire, amounted to about 810,000,000 tons. Had this been coked in by-product ovens the volatile nitrogen of the coal would have yielded 23 pounds of ammonium sulphate per ton, or a total of 9,315,000 tons, which at $60 per ton would have had a value of $558,900,000. But this would not be all. Had this ammonia been recovered, it would have been used on the soil as a fertilizer, and the crops would have been increased fully 20 per cent and the saving would have been many millions more."

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[a] Pennock, J. D., Jour. Ind. and Eng. Chem., vol. 4, 1912, p. 172.

It certainly is startling to realize, if the total nitrogen content of bituminous coal is taken into consideration, that last year we saved less than $4,000,000 worth of combined nitrogen from this source, whereas more than $2,000,000,000 worth of that stored up for us ages ago was dissipated into the atmosphere in the uncombined condition. Of course, the recovery of even 10 per cent of this amount is with present knowledge impossible, but it is interesting to note that the public and the manufacturers themselves are being aroused to the loss, that by-product coke ovens are being employed more and more, and that the question of producing combined nitrogen from the atmosphere is making a real beginning. Here again Germany shows her preeminence in chemical economics, as four-fifths of all her coke is made in by-product ovens.

FIXATION AND RECOVERY OF NITROGEN.

As an offset to this great waste of nitrogen there are at present five different methods for bringing this element into combination, and a sixth has been proposed. Four, and perhaps five, of these processes have already reached commercial success, but the tremendous amount of energy at present required for their prosecution raises an effective barrier against ever really offsetting the wastes that are taking place.

It is scarcely necessary to present details of the processes for obtaining nitrogen in the form of cyanamide as practised at Niagara Falls and abroad, or to describe the processes of Birkeland and Eyde, of Pauling, or of Schoenhof (Badische Anilin und Sodafabrik process) which obtain nitric acid from the air by means of the high temperature of the electric arc, and absorb the acid in lime to be sold as calcium nitrate; or to repeat the published statements in regard to the Serpek patents for converting kaolin or bauxite into nitrides and then into ammonia, or in regard to the Haber method for the direct union of nitrogen and hydrogen under the influence of pressure and a catalytic agent.

It may be well to state that cyanamide is obtained by the action of nitrogen on calcium carbide heated to 1,200° C., a temperature at which it rapidly absorbs the gas and forms cyanamide. It is necessary, however, first to produce calcium carbide and to obtain pure, dry nitrogen free from oxygen, which is done by liquefying air. The cost of these operations is the chief limitation of the process. It is true that there are now large wastes of almost pure nitrogen from the carbonating towers of soda plants, amounting to 2,940 tons per day,[a] and in the air residues in the production of sodium peroxide, but these wastes are not yet available for cyanamide plants, owing to conditions of transportation and power.

Of the three processes for the union of nitrogen and oxygen at the elevated temperature of the electric arc the Birkeland and Eyde process at Notodden, Norway, has been so far the most successful perhaps because of cheap electric power and the use of many large furnaces. In 1910 the Notodden plant utilized some 50,000 kilowatts of electricity throughout the year, an amount that has probably been increased to 200,000 kilowatts. The output approximates 70 grams of HNO_3 per kilowatt hour. The furnace has the great advantage of being capable of use in large units, some of which are of 4,000 horsepower. It produces nitric acid as calcium nitrate, which commands a ready market. The Pauling process is being used near Briançon, France, and appears to be in successful operation. An American plant using this process has recently begun operations at Nitrolee, S. C. The Schoenhof process is to be installed in new works in Norway, together with the Birkeland and Eyde process, and it is estimated that the two processes will shortly be using 250,000 horsepower in that country. Even this tremendous expenditure of energy can, however, supply only a fraction of the world's requirements for combined nitrogen, as one kilowatt year is required to produce 1 ton of 13 per cent calcium nitrate.

The success of the above-named processes at the present time is dependent almost solely on the factor of cheap energy. The principle of all is the same, namely, the utilization of the intense heat of the electric arc to bring about a reaction between nitrogen and oxygen and the quick cooling of the gases in order that the reaction may not reverse itself. In the Birkeland and Eyde process the electric arc is branched out by means of an electric field; in the Schoenhof process a similar active surface is obtained by producing in tubes long arcs up to 22 feet in length. In the Pauling process the arc is enlarged by means of a blast of hot air under pressure. Patents recently issued in Germany indicate that an entirely new method may soon be used, depending upon the reaction between nitrogen and hydrogen under pressure with the reaction hastened by uranium or some catalytic agent, the ammonia being absorbed as fast as produced. An inestimable advantage will be gained by procuring some method by which nitrogen can be fixed without the tremendous loss of energy involved in heating it to 3,500° C., the temperature required in the electric processes.

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[a] Loc. cit.

The Serpek process, which is operating in France, treats a mixture of bauxite and excess carbon with air at high temperatures, resulting in the formation of nitrides, which, when treated with water or caustic soda, yield ammonia and oxides or hydroxides. The process was started with the idea of producing pure alumina as the main product and ammonia as a by-product, but the nitrides of impurities, especially of titanium and iron, have not been removed as easily as anticipated. A similar process employing the medium of aluminum nitride is being developed in this country, but no information has been published relative thereto. There is every reason to expect the success of a method using nitrides. Such a method is especially desirable because it will probably require much less energy than the direct-combustion methods.

It would seem that if bacteria can bring about the fixation of nitrogen on the roots of legumes, man also must sooner or later succeed in bringing about this reaction at moderately low temperatures and perhaps in time imitate the process through the use of catalytic agents.

WASTE AND UTILIZATION OF SULPHUR.

The waste and the utilization of sulphur are both enormous and depend largely on local conditions. We produce sulphur cheaper than any other country in the world, sell it at perhaps the highest price, and in the form of sulphur dioxide discharge it into the air from the stack of a single smelter in quantities almost as large as those utilized throughout the country from sulphur and domestic pyrite put together. If the sulphur discharged into the air from this one smelter were converted into sulphuric acid it would furnish more than enough sulphuric acid for the total fertilizer industry of the United States. This country is producing annually about 3,000,000 tons of sulphuric acid—the basis of all chemical industry—of which approximately one-half is used in the manufacture of fertilizers. The total amount of sulphur dioxide discharged into the air in this country would unquestionably suffice to make more than 8,000,000 tons of sulphuric acid. That the sulphur dioxide from smelter smoke can be recovered has been proved at zinc smelters and by the copper smelters of Tennessee, but the question of economical recovery is so closely connected with the question of transportation and markets that at present the idea of converting sulphur dioxide into sulphuric acid in sufficient quantity to fully utilize the waste gases seems almost hopeless for the western smelters. Indeed, if the total output were made into sulphuric acid it would probably at present become a worse nuisance than the gases themselves, although the growth of the fertilizer industry in the West may largely solve the problem.

In the South, where the major part of the fertilizers made in this country is used, the sulphur fumes from two large smelters, which are near the phosphate markets, are being successfully utilized. At the present time probably 200,000 tons is recovered as a by-product in the roasting of zinc sulphide in regions where the sulphuric acid can find market, and probably 300,000 tons is recovered as a by-product in the smelting of copper; at the same time a great nuisance to the surrounding country has been largely mitigated. The smelting plants of the West are fortunate in having, comparatively near, immense deposits of phosphate rock which can be used for making phosphates as soon as a western market for the product is developed. Since, however, the western smelting plants are meeting much legislation against the passage of smelter fume into the air, and since the production of sulphuric acid can at best be only a partial remedy, other methods of disposing of their sulphur and waste material seem at least temporarily necessary.

Prof. Cottrell, whose process for the precipitation of solids from gases has recently been turned over to a research corporation under the auspices of the Smithsonian Institution, takes up this question in an interesting manner in an article on "Mineral losses in gases and fumes."[a] He refers not only to the outlet through superphosphates, but also to a process [b] for fixing the sulphur in harmless compounds by utilizing the fumes to decompose finely granulated and moistened basic slag and simultaneously to leach out any metal values that the slag contains. Prof. Cottrell also refers to a second process, now attracting much attention,[c] in which the sulphur dioxide is reduced to elemental sulphur, which can be stored indefinitely, and he suggests that this sulphur might be utilized as a binding material for sand in the manufacture of drainage tile or for other uses of a like character to which it is not now applied on account of its price. Indeed, at the present time sulphur is being used in Philadelphia as a cementing material in which to set the trolley posts of the street-car lines. These trolley posts were formerly greatly corroded by electric currents and electrolytes in soil moisture, but the sulphur, being itself an insulator and being waterproof, appears to protect the iron and makes an excellent cementing material. Indeed, sulphur may possibly find much more extended use to preserve iron from the effects of electrolysis than has heretofore been imagined.

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[a] Cottrell, F. G., Mineral wastes symposium, Jour. Ind. and Eng. Chem., vol. 4, 1912, p. 183.

[b] The Westby-Sorensen process (by E. P. Jennings). Eng. and Min. Jour., vol. 86, Aug. 29, 1908, p. 418.

[c] Young, S. W., Thiogen process for reduction of sulphur dioxide in smelter fume. Min. and Sci. Press, vol. 102, 1911, p. 336.

Prof. Cottrell also hopes that the pyritic smelting of copper in the blast furnace may be found to be possible with a smaller consumption of oxygen, in order that a considerable percentage of the sulphur may be sublimed without oxidation. If this result could be accompanied by the utilization in part of superheated steam in the copper converter so that there, too, some of the sulphur might be recovered without oxidation the problem would be a long way toward solution. Certainly the necessity of importing nearly $3,000,000 worth of pyrite each year is greatly to be regretted while these immense sulphur wastes continue.

LOSSES IN THE UTILIZATION OF MATERIALS FOR POTTERY ENAMELS AND CEMENT.

The cause of conservation can not be forwarded by any other one agency in a degree comparable with the influence that the various products of our silicate industries bring to bear. Bleininger[a] has brought out this fact clearly. The chief raw materials that enter into the manufacture of clay products are absolutely inexhaustible. The deposits of clay, limestone, sand, feldspar, soda, and other basic material are unlimited and the minor materials, such as fluorspar, cryolite, niter, borax, and the various colors and opacifiers, can probably always be manufactured in sufficient quantity or substitutes can be found. The more these materials are used the greater will the saving be. These products are of the utmost importance in conserving fire risks through fireproof construction, in sanitation, in drainage, in bridges, culverts, and buildings, in the construction of permanent roadways and waterways, and in beautifying our homes and villages.

POTTERY.

One of the largest of our imports is pottery, the import value of which in 1910 amounted to $11,027,405, an increase of 40.73 per cent in 10 years. At the same time we produce in this country a still larger amount, chiefly of the coarser and less expensive kind, although potteries producing the very highest class of ware are developing rapidly. For our best ware much of the clay is imported, although there is little doubt that a careful study of our own deposits and methods of preparation would enable us to utilize domestic material more extensively than is done at the present time. This utilization is especially necessary, as some foreign countries threaten to prohibit the exportation of their special clays in the hope that thereby their own pottery industry will be protected.

The chief wastes appear to be in this use of more expensive foreign material when systematic study would undoubtedly enable our potteries to obtain all of their clays at home, just as they now obtain all of their feldspar and quartz. It is undoubtedly further true that intelligent management would enable potteries to use material that is not now available, especially the semikaolinized feldspars of the southern Appalachian region. Investigations now under way by the Bureau of Mines seem to indicate that there is no question that an immense tonnage of this material, heretofore considered of no value, may be readily utilized. Much of this material, with little additional expense, can be obtained in the same pits or mines from which kaolin is now taken. These semikaolinized feldspars are simply mixtures of kaolin and feldspar and are some of the purest known, being as free from impurities and yielding as white products as any found in the world. If the potteries could obtain this feldspar and this kaolin separate, they would themselves mix the materials according to their formulas to produce the highest class of ware. There seems no good reason why the materials should not be utilized by adding pure kaolin or pure feldspar to bring the mixture to the desired composition. Careful technical control is all that is necessary. Probably 200,000 tons of the purest material, which now goes to waste, can be utilized under scientific management, with advantage both to the producer and to the consumer.

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[a] Bleininger, A. V., The relation of the silicate industries to conservation. Jour. Ind. and Eng. Chem., vol. 4, 1912, p. 180.

Prof. Bleininger states that the chief loss in the ceramic industry at present is a loss of heat efficiency, and calls attention to the fact that in Germany special continuous kilns are used that effect a saving of heat of 50 to 70 per cent, whereas in this country periodic kilns are still used almost exclusively. He notes further that less than 20 pounds of coal out of every 100 used was actually applied to heat the ware.

ENAMELS AND GLAZES.

Glazed ware and enameled ware have a direct bearing upon proper sanitation and public health and their use should be encouraged in every way. They also serve as protective material for conserving metals, and they afford a ready market for such substances as antimony oxide, zirconium oxide, and borax. They are easily produced, and more general information in regard to them and their manufacture should be published, so as to make possible a cheaper production of enameled articles. Furthermore, enamel brick and tile, which are becoming more and more important from a standpoint of beauty as well as utility, can still be greatly improved, and much of the work now done by hand can be done by machine.

CEMENT.

The wonderful effect of the growth of the Portland-cement industry on the wastes of other materials can not be overestimated. In 15 years the output of Portland cement in this country alone has developed from less than 1,000,000 to nearly 80,000,000 barrels per year. The industry has supplied a cheap material which not only replaces iron and steel in much structural work but also is used as a coating for them, greatly increasing the life of the metal by protecting it from rust. Cement in the form of concrete has taken the place of millions of feet of lumber and gives a permanency to our structures that wood can not give. Not only is it used in our large engineering structures, but it is used for hundreds of minor purposes around the farm and the village. Indeed the concrete dwelling is becoming more and more in vogue, and with its comparative fireproof and weatherproof qualities, together with new methods for coloring and decorating, it promises to supplant the ordinary wooden house.

The development of the cement industry has been accompanied by keen competition and careful attention to detail, so that, fortunately for the people, the price of the product has been brought down to the low rate at which it can be obtained to-day.

The kilns have been gradually increased in size until a kiln 100 to 140 feet long is the rule rather than the exception, and much larger output and saving of heat has undoubtedly accompanied each increase in length and size. Still, to the ordinary observer there appear to be heat losses that ought to be prevented by some regenerative process. In most cement works the raw rock before being ground is dried in a separate kiln, while from the main kiln incandescent gases escape into the stack. The white-hot clinker falling from the front end of the kiln has to be raised to towers through which it slowly falls to be cooled, and here again there are immense losses of heat for which no practical method of utilization has yet been found.

Another loss which is much more serious than is generally realized is the flue dust that passes from the end of the kiln into the stacks and away. Actual measurement indicates that this flue dust is probably never less than 4 per cent of the raw material used and that in some plants it is more than 10 per cent. The loss is of particular importance because the material has been ground. Schott[a] states that this dust is being caught and recharged with profit in some of the German plants. In this country some of the cement manufacturers are threatened with restrictive legislation, and three plants at least have been ordered to shut down or put in dust catchers to eliminate a nuisance. A plant at Riverside, Cal., has already installed the Cottrell process for catching its dust, which was injuring the surrounding orchards so seriously that the plant had no choice but to catch the dust or to shut down. In this plant the raw material carries a small amount of feldspathic rock, and as a consequence the alkali that it contains is volatilized and caught with the dust in the collectors. This dust averages about 2 per cent soluble potash, but certain samples obtained under peculiar working conditions have analyzed as high as 35 per cent soluble alkali, of which about one-half was potash. These figures show plainly, as indeed has been known for some time, that in the cement kiln the alkalis are for the main part volatilized. Moreover, it would certainly seem possible to increase the amount of potash-bearing material in the mix by the addition of either potash feldspar or such potash-bearing silicates as the green sands of New Jersey, without injuring the quality of the cement obtained and without adding to the cost of manufacture. With the catching of the dust it would then seem possible to obtain a by-product rich in potash, the value of which might cover wholly or in part the cost of eliminating a dust nuisance.

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[a] Schott, Otto, Dust in Portland cement plants. Cement and Eng. News, vol. 24, February, 1912, p. 40.

UTILIZATION OF FULLER'S EARTH.

The imports of English fuller's earth are regularly increasing in spite of the duty. Domestic production is still used chiefly for petroleum, whereas imported earth is used for edible oils. The deposits of fuller's earth in the South, especially in Georgia, South Carolina, and Alabama, are immense, and there is no good reason why any foreign earth should be imported. Deposits in Arkansas and Texas are also being exploited. Domestic earth could be easily produced at a profit at the present price if a sufficient output could be maintained. Several of the domestic earths bleach edible oils much better than the English. Lack of knowledge of methods of preparation for the market is one of the chief reasons why the domestic earths are not now used; also some manufacturers do not yet successfully remove from edible products the slight taste these earths are apt to impart. At least one large producer of edible oils now uses only American material.

INFUSORIAL EARTH.

Probably the largest deposit of fuller's earth in the world is at Lompoc, Cal. It is almost inexhaustible and is remarkably free from iron and other impurities. The earth is used in making light terra-cotta brick; in the beet-sugar industry it is used to assist in filtration, and it is also used as a boiler covering. The pure earth has been rather hard to obtain in the past, but the immense deposit at Lompoc, much of which is still open to exploitation, should encourage new uses for the material. Like many other deposits in the West, the cost of transportation is the chief obstacle to its present development. If it could be delivered at a low enough price on the Atlantic seaboard, it would undoubtedly find extensive use as an insulating material, and be an effective agent in preventing heat losses.

NEW USES FOR ASBESTOS.

The uses of asbestos are rapidly increasing. They afford protection against fire and are effecting a real conservation of lumber. Asbestos shingles, asbestos plaster, and asbestos lumber are of the utmost importance, and their use should be encouraged. They are much less easily destroyed by atmospheric agencies than is wood and they are noncombustible. In building operations asbestos products have the advantage over ceramic products in that they can be sawed and nailed. With the aid of asbestos lumber it is now possible to erect and even to decorate a complete building without having wood or any combustible material in its structure. This country, however, produces at the present time a very small proportion of the asbestos it uses, although extensive deposits are known to exist in Wyoming. Recently new deposits have been opened up in Texas, and some of the best asbestos known for electrical purposes is said to occur within the Government reservation of the Grand Canyon.

POSSIBLE PROGRESS IN THE MANUFACTURE OF REFRACTORY MATERIALS.

The industry of producing refractory materials offers an especially promising field of research. Many metallurgical furnaces have to be relined much more frequently than should be necessary, and while this relining is being done their operation must be suspended for weeks. A specific instance was recently reported in which the regular life of the furnace in an important industry was increased from six months to over two years simply by a careful study of the texture of the refractory bricks used and by the development of methods for decreasing their porosity. Great improvements have taken place in the past few years, but few careful scientific investigators have attacked the problem. Bauxite bricks offer an especially promising field if their cracking under contraction and expansion can be controlled—a result by no means improbable, for already one producer claims to have accomplished it. Furthermore, by the addition of alumina to the clay from which they are made it is quite possible that the best fire clays can be greatly improved and brick be made from them approaching in composition bauxite brick. There are also large quantities of highly aluminous clays in the bauxite regions of Georgia and Arkansas, which on investigation may prove to be highly valuable for refractory purposes. Some recent work by thoroughly competent experimenters[a] indicates an awakening interest in the subject. The need for special refractories has been forced home by the much higher temperatures demanded in the chemical and ceramic industries. Indeed, the field of the electric furnace is limited chiefly by the ability of the furnace walls to resist heat. According to FitzGerald[a] brick made from special forms of silicon carbide and from electrically calcined magnesia have shown most excellent resistant properties. In this connection, there is a growing demand for zirconia, and an abundant and cheap supply of this material, or of any of the cerium group of earths, would prove highly important to electric-furnace development.

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[a] Rigg, Gilbert, Defects in refractory brick and their causes. Met. and Chem. Eng., vol. 8, May, 1910, pp. 237–240, also vol. 8, Oct., 1910, p. 562; Saunders, L. E., Electrically fused alumina. Trans. Amer. Elec. Chem. Soc., vol. 19, 1911, p. 333; FitzGerald, F. A. J., Refractories. Met. and Chem. Eng., vol. 10, Mar., 1912, pp. 129–132.

THE WASTE OF ARSENIC.

According to Harkins and Swain,[b] about 30 tons of arsenic trioxide goes out of the stack of the Washoe smelter daily. This quantity means perhaps 80 to 90 per cent of the total arsenic coming into the plant, and, if correct, amounts to over 10,000 tons a year that is being thrown into the atmosphere by this smelter alone. Similar losses are taking place in almost every smelting plant in the country, and there is no doubt that over 25,000 tons of arsenic goes to waste each year. The output in 1911 increased nearly 300 per cent over that of 1910, chiefly because of the requirement put upon smelters for the collection of the arsenic formerly allowed to escape. Although the price has been greatly reduced, the oversupply is not being easily marketed.

Arsenic is used in large quantities in combination with lead as an insecticide, and experiments would seem warranted to determine whether arsenic sulphide or calcium sulpharsenite, both of which are probably quite harmless to plants, may not be substituted for lead arsenate, giving a much cheaper insecticide that uses more arsenic and conserves lead. Obviously, any proposed insecticide must not only be effective as a poison, but also must not injure the foliage of the plant upon which it is placed.

THE SUPPLY OF BROMINE AND CHLORINE AND THE NEED OF NEW USES.

There is apparently an overproduction of both bromine and chlorine in this country, and new uses are desired as an outlet for these elements. Bromates are incidentally made in the production of bromides and so far have had little market. Potassium bromate, however, is an excellent oxydizing agent, and its use for this purpose would seem possible of great extension. One to two pounds of potassium bromate added to each ton of solution of potassium cyanide in the cyanide process for gold is said to keep the bath "sweet," provided the bath is kept alkaline with lime. Any sulphides, sulphocyanides, or ferrocyanides tending to reduce the value of the dissolved oxygen are seemingly prevented from forming by the presence of potassium bromate.

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[a] Loc. cit.

[b] Swain, R. E., and Harkins, W. D., Arsenic in vegetation exposed to smelter smoke. Jour. Amer. Chem. Soc., vol. 30, June, 1908, p. 915.

Chlorine can now be obtained very cheaply in liquid form and can be supplied either in regular cylinders, in cheap cylinders that do not have to be returned, or even in tank cars. Processes are also being exploited which produce the chlorine on the ground electrolytically. These processes, although cheapening the application, tend also to reduce the market for the chlorine manufactured as a regular product. A possible use for chlorine is for chlorinating certain pyroligneous tars to be used in the preservation of wood. It may be possible also to make cheap, noncombustible solvents by chlorinating certain petroleum residues, like the cheap solar oil of Texas, which can now be disposed of for only about 2 cents a gallon. Such solvents, especially if they do not attack metals, are greatly needed. Immense quantities of chlorine in the form of calcium chloride are being run off as a waste from the ammonia soda process works of the country. One plant alone now produces daily 280 metric tons of calcium chloride, 90 per cent of which is a total waste. Ten per cent is, however, evaporated and used in granulated form, chiefly in refrigerating plants and on roads to lay dust. This material is also found to be of great advantage if sprinkled in coal mines, as it tends to keep the coal dust moist, and thereby greatly diminishes the danger of explosions. Any nonhydroscopic substance added to water used to sprinkle coal dust in mines has little more effect than that of a diluent. Water itself quickly evaporates from coal dust in dry mines, and is carried away by the ventilating currents. If calcium chloride be added, the moisture is, of course, retained.

RARE EARTHS AND THEIR USES.

Comparatively little is known about a large number of the rarer elements of which the earth is composed. Even the minerals that contain them are little known and it is impossible to state how extensively they occur in the West, for they may have been overlooked as worthless. This assumption is especially true of such elements as tungsten, vanadium, titanium, tantalum, columbium, thallium, thorium, beryllium, and the 20 or more elements of the cerium and yttrium earths. No one can say what an exploitation of this field might lead to, but it is through pure scientific investigation of such problems as these that many industries have been developed, perhaps the most noteworthy being that of the Welsbach gas-light mantle. In the production of thorium from monazite, by far the larger part of the associated materials go to waste. About 30 per cent of this waste is cerium and the remainder lanthanum, neodymium, praseodymium, and other rarer elements of the rare earths. There is every prospect that the cerium will soon be utilized and bring a fair price. The separation of the element from the other earths is no longer difficult and, once the element is in solution, can be brought about in a single operation. The properties of the metal in alloys some of which have most remarkable pyrophoric properties,[a] are now well known and the metal can be readily reduced by the electric current. It is also probable that cerium oxide, lanthanum oxide, and the oxides of other rare earths that occur in these waste materials will become of special value as refractories, for they are among the most infusible materials known. Cerium is also finding use in the form of cerium fluoride in the flaming arc, and there is little doubt that this use may be greatly extended. The properties of some of the compounds of cerium to act as perhaps the strongest oxidizing compounds known may open up new uses for this metal.

MISCELLANEOUS.

Large and extensive deposits of barite occur in Missouri, California, and Nevada, but transportation costs make possible large imports of this valuable mineral. It is used in large quantities in the production of lithophone and in paints, and should be made to supply at least a goodly portion of the western demand for these materials. Recently opened deposits in central Kentucky are already entering into active competition with the foreign article, and as these, together with other deposits being mined in Tennessee, North Carolina, Virginia, and Georgia, can obtain lower freight rates to the eastern markets it is to be hoped that they may be able to supply all the needs of those markets. Large amounts of barite occur in some of the metalliferous ores of the West. The mineral has a high specific gravity, is difficult to separate, and has to be fluxed off; consequently it passes into the slag pile.

Apatite is associated with the magnetite iron ores of New York, and is left behind by the magnetic separators. Hundreds of thousands of tons of such waste have accummulated, containing about 30 per cent of phosphoric acid in the form of apatite mixed with hornblende and quartz. No economical method of further concentration has yet been found.

Mica is always in demand, especially in large sheets, or in scrap with low iron content. Mica scrap heaps at the exits of old mines have all been carefully reworked on account of the excellent insulating material they contain, as well as for the production of other products in which scrap mica has been utilized.

Immense deposits of graphite have not been available, on account of the impossibility of separating the mineral from the gangue, but it has been found that in many cases simple pulverizing and sifting through sieves will separate the fine granular gangue from the more flaky graphite. Also, both of the new processes mentioned (p. 27) as being used for the separation of molybdenite are claimed to be equally effective in separating graphite from its accompanying impurities.

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[a] Hirsh, A., Jour. Ind. and Eng. Chem., vol. 3, 1911, p. 880.

Calcium also can be readily and cheaply obtained whenever a use for this metal is found. The available resources are absolutely inexhaustible, but only in recent years could the element be separated electrolytically.

Lithium carbonate is now a comparatively cheap substance, which could be produced in much greater quantities if more extended use were found. At present it is used only in medicine and in one of the latest forms of storage batteries which is now becoming prominent in the market.

Selenium and tellurium can be obtained in much greater quantities than is generally supposed. From our copper refineries and sulphuric-acid plants at least 300,000 pounds of selenium is going to waste each year. Up to a year or two ago no important use for selenium was known, although for some three or four years it had been secretly used in the glass industry. It is now known to be used to color glass red, and in small amounts to decolorize glass by neutralizing the green of ferrous iron. It is obtained as a by-product in the refining of copper. Probably about 20 tons per year now finds place in the arts. Selenium is the only known element having an electrical conductivity that varies with exposure to light. This property will undoubtedly give the metal especial prominence in the future, as its applications are developed. It is now used in automatic gas-light apparatus, especially on gas buoys, in a new selenium photometer, and in devices by the use of which the transmission of pictures by wire is proposed.

Tellurium is also going to waste in quantities comparable with the waste of selenium. No use of importance is known for the element, although it is obtainable at a low price and many tons a year could be furnished.

Silicon, next to oxygen, is the most abundant of all elements, and until recently has been obtained only as a chemical curiosity. It has wonderful powers of resistance to all ordinary weathering agencies, and if it could be applied as an impervious coating to rigid perishable materials, should greatly prolong their life. It has also some wonderful properties of resistance to chemical agents, is easily made, and except for its brittleness would probably find extensive use. Even now, however, uses are gradually developing, one of the most interesting of which is for the shoes of plows in certain acid or pyrite furnaces in which iron rapidly goes to pieces. Many tons of this element is used in alloy with iron, especially in electrical transformers. It reduces hysteresis losses and increases resistance.

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Bulletin 48

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE SELECTION OF EXPLOSIVES
USED IN
ENGINEERING AND MINING OPERATIONS

BY

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AND
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WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

First edition, February, 1913.

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THE SELECTION OF EXPLOSIVES USED IN ENGINEERING AND MINING OPERATIONS.

By Clarence Hall and Spencer P. Howell.

GENERAL STATEMENT.

This bulletin deals with the characteristic features of the principal explosives used in mining and engineering operations, and especially with the tests that show the suitability of different classes of explosives for different kinds of work. The Bureau of Mines publishes the report as one of a series dealing with tests of explosives and methods of reducing the risks involved in the use of explosives in mining operations.

The application of explosives to engineering and mining operations has increased rapidly in recent years. According to a preliminary report issued by the Bureau of the Census, 469,000,000 pounds of explosives was manufactured in this country during the year 1909, and the greater part of this production was used for industrial purposes.

In large engineering projects and in mining operations requiring the use of explosives the selection of a suitable explosive from the many varieties offered for sale is of fundamental importance. Various considerations are involved in the selection of an explosive of proper class for the blasting to be done. Many explosives suitable for quarry work are unsuitable for use in deep mines or in close workings. In metal mining and in driving tunnels the character of the gases evolved by the explosive on detonation is an important consideration. An explosive for use in gaseous or dusty coal mines must be formulated and compounded so that its flame temperature and the height and duration of its flame are reduced enough to permit its being used with comparative safety. In wet workings or in submarine blasting explosives impervious to moisture are requisite. In extremely cold climates explosives that do not require thawing are desirable, provided they are equally good in other respects. An essential requirement of all explosives, especially of those for use in tropical countries, is that they shall remain stable without change in chemical or physical characteristics.

Because of the varying conditions in the different projects on which explosives are used, it is necessary to emphasize the fact that some characteristics of explosives are of much importance in certain classes of work and of little or no importance in others.

EXPLOSIVES USED IN QUARRY OPERATIONS.

Practically every class and every grade of commercial explosive are used in open-air work to meet varying conditions. In breaking down rock in quarries the explosives generally employed are: Black blasting powder, granulated nitroglycerin powder containing 5 to 15 per cent of nitroglycerin, "straight" nitroglycerin dynamites containing 15 to 60 per cent of nitroglycerin, low-freezing dynamites commercially rated according to the equivalent percentage of strength of the "straight" nitroglycerin dynamites, and ammonia dynamites rated in a similar way. In recent years blasting gelatin, gelatin dynamites, ammonium-nitrate powders containing nitro-substitution compounds, chlorate powders, and the so-called nitrostarch powders have been used to a small extent in quarry work.

BLACK BLASTING POWDER.

Black blasting powder is a mechanical mixture; it consists of finely pulverized sodium nitrate intimately associated with combustible materials. This intimate association of the materials is brought about by thoroughly mixing and incorporating them in what are technically termed wheel mills. The product is pressed into hard cakes, which are subsequently broken into small grains. The powder is then put in a revolving barrel where the grains are rounded by rubbing together, and at the same time are coated with graphite or, as the operation is often termed, "glazed." The object of rounding and glazing the grains is to render them free-running; the glazing also serves to delay somewhat their taking up moisture from the air.

The following is the composition of the black blasting powder that is generally offered for sale in this country:

Composition of commercial black blasting powder.

Charcoal	16
Sulphur	11
Sodium nitrate	73
	[a] 100

The powder is divided into sizes according to diameter of grain, the sizes being separated and collected by sieves of different mesh. The sizes most usually offered for sale are called CC, C, F, FF, FFF, and FFFF. Of these CC represents the largest grains, about one-half inch in diameter, and FFFF represents the smallest grains, about one-sixteenth inch in diameter.

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[a] A small percentage of water is included.

GASES AND PRESSURE PRODUCED ON EXPLOSION.

When blasting powder is ignited in a drill hole a rapid combustion takes place, and it is the pressure of the highly heated gases formed that disrupts the rock. It has been found that 150 liters (5.30 cu. ft.) of gas is produced from 454 grams (1 lb.) of black blasting powder, the gas being measured at normal temperature and pressure, 0° C., and 760 mm. When this volume is compared with the volume of permanent gases produced by the detonation of equal weights of nitroglycerin dynamites, it becomes evident that in a consideration of the energy developed by explosives there are other factors of more importance than the volume of permanent gases evolved.

At the instant of explosion the gases evolved are highly heated and tend to occupy a much greater volume than at normal temperature and pressure. Since the maximum theoretical temperature produced by the detonation of dynamite is much higher than that produced by the explosion of black blasting powder, the gases evolved on the detonation of dynamite are more highly heated and tend to expand more strongly than those evolved by black blasting powder.

TIME FACTOR.

The factor of time must also be taken into account in considering the power developed by explosives. The rate of detonation, explosion, or burning determines the characteristic effects of commercial explosives. This rate is the governing factor in judging relative efficiency, and offers the best basis for selecting explosives suitable for various mining conditions. The shattering effect of sudden pressure on a given substance is very different from that produced by an equal pressure applied slowly. The quicker the rate of the explosive reaction the more pronounced will be the shattering effect. The shattering effect of a commercial explosive depends on its rate of detonation.

During the conversion of an explosive into solid, liquid, and gaseous products the expansion of the gaseous products and the cooling effect of the walls of the drill hole or other heat-absorbent surroundings tends to reduce the temperature of the gases, so that the theoretical temperature or maximum pressure is never reached. The more nearly instantaneous the explosion reaction for a given explosive, all other conditions being equal, the greater is the volume of highly heated gases it produces in unit of time and the more violent is the effect it exerts.

The rate of burning of FF black blasting powder, as determined at the Pittsburgh testing station under conditions simulating those that prevail when powder explodes in a drill hole, has been found to be 469 meters (1,538 feet) per second. This rate is slow compared with the rate of detonation of "ordinary" dynamites. Inasmuch as the gases from the combustion of black blasting powder form at such a relatively slow rate, the pressures produced are prolonged and there is a corresponding loss of heat and pressure from conduction and radiation. Black blasting powder is, therefore, best suited for work in which a gradual pushing or heaving effect is desired. In order to obtain the maximum efficiency of black blasting powder the charge must be well confined by suitable stemming. The most successful results are obtained when the drill holes are tamped to the mouth.

Black blasting powder is used in excavating cuts, quarrying soft rock or stone, and especially in quarries where large blocks of building stone are sought. In some work it is necessary to chamber or hollow out the bottom of the drill hole with dynamite or other suitable high explosive, and thus make a large cavity at the point where the powder can be placed to best advantage. When drill holes are enlarged in this way they become hot, hence they should not be loaded immediately after chambering, as the heat may explode the powder charge prematurely.

GRANULATED NITROGLYCERIN POWDERS.

The following composition is an example of a granulated nitroglycerin powder that is offered for sale in this country:

Composition of commercial granulated nitroglycerin powder.

Nitroglycerin	5.0
Combustible material [a]	35.0
Sodium nitrate	60.0
	100.0

The composition of the basic grains of granulated nitroglycerin powders is somewhat similar to that of black blasting powder. Instead of the nitrate and the combustible materials being thoroughly incorporated, these ingredients are heated to a temperature at which the resin and sulphur melt. The sticky mass formed is then granulated by cooling while being rubbed through a fine-mesh screen.

The grains produced in this way are hard and porous; they can be superficially coated or have their interstices filled with a small proportion of nitroglycerin. To insure the maximum efficiency of a granulated powder it is necessary to detonate the charge with a priming cartridge of dynamite. The nitroglycerin superficially held in the interstices and on the outside of the powder grains detonates, and thus accelerates the combustion of the grains. The rate of detonation of granulated powder has been found to be 1,018 meters (3,339 feet per second), or more than twice that of black blasting powder. Consequently, granulated powder is more effective and gives better results than black blasting powder in soft and seamy rock or in material that does not sufficiently confine the gases evolved.

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[a] Consists of sulphur, coal, and resin.

"STRAIGHT" NITROGLYCERIN DYNAMITES.

The following compositions are examples of the "straight" nitroglycerin dynamites that are generally offered for sale in this country:

Compositions of "straight" nitroglycerin dynamites of various strengths.

Ingredients.	15 per cent.	20 per cent.	25 per cent.	30 per cent.	35 per cent.	40 per cent.	45 per cent.	50 per cent.	55 per cent.	60 per cent.
Nitroglycerin	15	20	25	30	35	40	45	50	55	60
Combustible material [a]	20	19	18	17	16	15	14	14	15	16
Sodium nitrate	64	60	56	52	48	44	40	35	29	23
Calcium or magnesium carbonate	1	1	1	1	1	1	1	1	1	1
	100	100	100	100	100	100	100	100	100	100

[a] Consisting of wood pulp, flour, and sulphur for grades below 40 per cent; wood pulp only for other grades.

The rates of detonation of 30 per cent and 60 per cent "straight" nitroglycerin dynamites have been found, by tests at the Pittsburgh station, to be, respectively, 4,548 meters (14,920 feet) and 6,246 meters (20,490 feet) per second.

The "straight" nitroglycerin dynamites as a class develop greater disruptive force than any of the other commercial types of explosives tested, and for this reason they should be used, whenever the conditions permit, for producing shattering effects or for blasting very tough or hard materials.

LOW-FREEZING DYNAMITES.

If the "straight" nitroglycerin dynamites are found to be too violent for certain classes of work, the low-freezing dynamites or the ammonia dynamites, which have lower rates of detonation and hence less disruptive effect, may be used to advantage. The following table shows typical compositions of low-freezing dynamites:

Compositions of low-freezing dynamites of various strengths.

Ingredients.	30 per cent strength.	35 per cent strength.	40 per cent strength.	45 per cent strength.	50 per cent strength.	55 per cent strength.	60 per cent strength.
Nitroglycerin	23	26	30	34	38	41	45
Nitrosubstitution compounds	7	9	10	11	12	14	15
Combustible material [a]	17	16	15	14	14	15	16
Sodium nitrate	52	48	44	40	35	29	23
Calcium or magnesium carbonate	1	1	1	1	1	1	1
	100	100	100	100	100	100	100

[a] Composition similar to that in the "straight" nitroglycerin dynamites.

The low-freezing dynamites have the advantage of not freezing until exposed to a temperature of 35° F. or less, but, like all nitroglycerin explosives, after they become frozen they must be thawed before use in order to insure the most effective results.

AMMONIA DYNAMITES.

The ammonia dynamites, compared with the other dynamites, have the disadvantage of taking up moisture very readily, because ammonium nitrate is deliquescent, and care should be observed when they are stored or used in wet places.

The following table shows typical compositions of ammonia dynamites:

Compositions of ammonia dynamites of various strengths.

Ingredients.	30 per cent strength.	35 per cent strength.	40 per cent strength.	50 per cent strength.	60 per cent strength.
Nitroglycerin	15	20	22	27	35
Ammonium nitrate	15	15	20	25	30
Sodium nitrate	51	48	42	36	24
Combustible material [a]	18	16	15	11	10
Calcium carbonate or zinc oxide	1	1	1	1	1
	100	100	100	100	100

[a] Composition similar to that in the "straight" nitroglycerin dynamites of the grades below 40 per cent.

GELATIN DYNAMITES.

The gelatin dynamites have been used to a large extent in wet blasting, as in the removal of obstacles to navigation and in deep workings, and as a general rule are best suited for these purposes. In the manufacture of these dynamites the nitroglycerin is gelatinized by the addition of a small percentage of nitrocellulose. The jelly-like mass thus formed is impervious to water. By the addition of different percentages of suitable absorbents the various grades of these dynamites are made.

The following compositions are examples of gelatin dynamites generally offered for sale in this country:

Compositions of gelatin dynamites of various strengths.

Ingredients.	30 per cent strength.	35 per cent strength.	40 per cent strength.	50 per cent strength.	55 per cent strength.	60 per cent strength.	70 per cent strength.
Nitroglycerin	23.0	28.0	33.0	42.0	46.0	50.0	60.0
Nitrocellulose	0.7	0.9	1.0	1.5	1.7	1.9	2.4
Sodium nitrate	62.3	58.1	52.0	45.5	42.3	38.1	29.6
Combustible material [a]	13.0	12.0	13.0	10.0	9.0	9.0	7.0
Calcium carbonate	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] Wood pulp is used in 60 and in 70 per cent strength gelatin dynamite. Sulphur, flour, wood pulp, and sometimes resin are used in other grades. Some manufacturers replace a small percentage of the nitroglycerin in these grades with an equal amount of ammonium nitrate. This replacement, however, offers little, if any, advantage other than reducing the cost of manufacture.

EXPLOSIVES USED IN MINING AND TUNNELING OPERATIONS.

It is generally recognized that in driving tunnels, sinking shafts, and in removing hard rock in metal mining, explosives having a high disruptive force are preferable. In work of this kind the cost of drilling holes is an important item. It has been found more economical to drill a few holes and to load them with an explosive of high disruptive force than to drill a number of holes and use weaker and cheaper explosives. It is important that explosives used in this class of work should produce the minimum amount of poisonous gases.

From what has been said about the composition and the characteristics of the different classes of explosives, it is evident that black blasting powder, granulated nitroglycerin powders, low-freezing dynamites, and ammonia dynamites would not be suitable or satisfactory for use in work of this kind, for they do not develop the requisite disruptive force; furthermore, these explosives, in common with the straight nitroglycerin dynamites, produce poisonous gases which vitiate the atmosphere of the working places.

PRODUCTS OF EXPLOSION.

At the Pittsburgh testing station the Bichel pressure gage,[a] used for determining the theoretical maximum pressures developed by explosives, is also used for collecting the gaseous, liquid, and solid products of explosion. The same method is used in preparing the charge and firing as in determining the maximum pressures developed, except that the indicator mechanism then used is replaced by a pressure gage. After the charge has been fired, the gases are allowed to cool for 30 minutes, the pressure is recorded, and the volume of gases at standard temperature and pressure (0° C. and 760 mm.) is computed. A differential sample of the gases is then taken over mercury by allowing the gases to escape gradually from the gage. The results of tests of various classes of explosives are tabulated below. A charge of 200 grams of the explosive in its original wrapper was used in all tests, except with black blasting powder, which was fired in charges of 300 grams.

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[a] For a description of the Bichel gage, see Bull. 15, Bureau of Mines, p. 103.

Combustion products resulting from tests of explosives in thin paraffined paper wrappers.[a]

[A. L. Hyde, analyst.]

Class and grade of explosive.	Electric detonator used. No.—	Weight of products of combustion (grams).			Gaseous products (per cent by volume).							Solids (per cent).		Volume of gas (liters).
		Gaseous.	Solid.	Liquid.	Carbon dioxide.	Carbon monoxide.	Oxygen.	Hydrogen.	Methane.	Nitrogen.	Hydrogen sulphide.	Soluble.	Insoluble.	
30 per cent "straight" nitroglycerin dynamite	6	96.8	102.1	12.9	22.9	28.4	0.0	20.6	0.7	27.4	.....	88.00	12.00	85.8
40 per cent "straight" nitroglycerin dynamite	6	107.4	87.1	12.4	27.3	26.9	.0	18.0	.4	27.4	.....	86.73	13.27	88.5
50 per cent "straight" nitroglycerin dynamite	6	124.6	70.3	14.7	24.4	31.2	.0	20.7	.7	23.0	.....	79.14	20.86	105.5
60 per cent "straight" nitroglycerin dynamite	6	143.5	49.6	11.9	22.2	34.6	.0	23.2	.8	19.2	.....	68.53	31.47	128.9
60 per cent strength low-freezing dynamite	6	161.5	43.5	3.9	8.9	47.4	.0	31.0	.6	12.1	.....	78.76	21.24	100.5
40 per cent strength ammonia dynamite	6	95.7	85.9	26.1	41.4	3.8	.0	3.1	.8	45.5	5.4	86.03	13.97	65.6
40 per cent strength gelatin dynamite	6	96.3	96.3	11.7	50.8	3.0	.0	1.8	.8	39.5	4.1	87.32	12.68	60.3
5 per cent granulated nitroglycerin powder[b]	6	115.5	93.6	8.3	51.3	2.7	.0	.9	.7	28.7	15.7	78.00	22.00	61.6
FFF black blasting powder	(c)	154.4	126.9	4.1	49.7	10.8	.0	1.8	.6	28.4	8.7	91.20	8.80	67.8

[a] The explosives named in this table are not of the same formulas as those in the tables on pages 8 and 9.

[b] Primer of 40 per cent "straight" nitroglycerin dynamite, representing 10 per cent by weight of the charge, was used, but the gases evolved by the dynamite were deducted in the computations of the volume of gas (liters).

[c] Black-powder igniter used.

The test results tabulated above show that gelatin dynamites on detonation produce the smallest percentage of poisonous gases (carbon monoxide and hydrogen sulphide). However, even that class of explosives is far from being satisfactory in this respect. Nevertheless, the gelatin dynamites are largely used in this country in metal-mining and in tunneling operations.

The ventilation in many metal mines and tunnels is defective, and yet the use of large quantities of explosives is necessary. Numerous accidents in deep workings have occurred from air vitiation caused by the poisonous gases evolved by detonating explosives. In one of the large western engineering projects 9 men recently were killed by the poisonous gases produced on the explosion of 40 per cent strength gelatin dynamite.

Soon after this accident the Bureau of Mines began studies of the noxious gases evolved on the detonation of explosives in order to discover whether the composition of explosives could be improved so as to increase safety in mining operations.

FORMULA FOR A MINE EXPLOSIVE.

From the foregoing statement it is evident that the only two classes of available explosives that develop the disruptive force required in removing hard rock in metal-mining and tunneling work are "straight" nitroglycerin dynamites and gelatin dynamites. To construct well-balanced formulas for the "straight" nitroglycerin dynamites it is necessary to reduce the percentage of combustible materials in order that there may not be a deficiency of oxygen. This reduction can be accomplished by replacing the wood pulp in the higher grades of these explosives with some inert material having a great absorbing capacity, such as magnesium carbonate or kieselguhr (infusorial earth), but as this method materially decreases the efficiency of the explosive by reducing the quantity of active matter, it was thought advisable to conduct experiments with gelatin dynamites, which do not require combustible material for absorbing the nitroglycerin.

Several samples of 40 per cent strength gelatin dynamite were procured from different manufacturers. All these samples produced poisonous gases on detonation, the percentage of carbon monoxide varying from 3 to 5.7 per cent and of hydrogen sulphide from 0.7 to 4.1 per cent.

The formulas for gelatin dynamites given on page 8 seem to provide for sufficient oxygen in the sodium nitrate to completely oxidize the combustible materials, and for this reason all the formulas are said to be well balanced. However, the gage tests showed that quantities of hydrogen sulphide were evolved on detonation and remained in the permanent gases. The sulphur used in the gelatin dynamites was held responsible for this result, and its elimination as an ingredient was necessary. The result of further investigations showed that paper wrappers heavily coated with paraffin, used in connection with the explosive and representing a comparatively large percentage by weight of combustible material, had not been given due consideration by the manufacturers of explosives. It was believed that by slightly increasing the percentage of the sodium nitrate sufficient oxygen would be provided to completely oxidize the hydrogen and carbon contents of the paper wrapper.

As a result of the investigations a quantity of 40 per cent strength gelatin dynamite was manufactured according to the following formula:

Special formula for 40 per cent strength gelatin dynamite.

Nitroglycerin	33
Nitrocellulose	1
Sodium nitrate	54
Combustible material[a]	11
Calcium carbonate	1
	100

---

[a] Flour.

The products of combustion were collected in the gage, 200 grams of the explosive in the original wrapper being used under the same conditions as in previous tests. The wrapper, like those of explosives previously tested, was paper coated with paraffin. The results of tests made with this explosive are shown in the following tables:

Combustion products resulting from tests of special 40 per cent strength gelatin dynamite.

[Analyst A. L. Hyde.]

WEIGHT OF PRODUCTS, GRAMS.

Gaseous	85.5
Solids	102.3
Liquid	13.2

GASEOUS PRODUCTS, PER CENT BY VOLUME.

Carbon dioxide	51.0
Carbon monoxide	.0
Oxygen	.9
Hydrogen	.0
Methane	.7
Nitrogen	47.4
Hydrogen sulphide	.0
	100.0

SOLIDS, PER CENT.

Soluble	92.10
Insoluble	7.90
	100.00

It will be noted that the above modified formula for 40 per cent strength gelatin dynamite on detonation in metal gages did not evolve poisonous gases. However, the question was raised as to whether such gases might not be evolved when large quantities of the explosive were detonated under actual mining conditions. It was then decided to supplement the gage tests by tests in mines.

MINE TESTS.

In taking samples of mine air after blasts with the older dynamites it was necessary for the investigators to use a breathing apparatus. The samples were taken by air displacement by means of small bellows, which was emptied and filled fifty times.

TESTS IN A LIMESTONE MINE.

The first experiments were carried out in a limestone mine at West Winfield, Pa. W. O. Snelling, consulting chemist of the Bureau of Mines, cooperated in the experiments. As the limestone in the mine mentioned was mined by the room-and-pillar method, the procedure followed was to shoot the rock "off the solid" with four or more shots, depending on the width of the face worked (figs. 1 and 2).

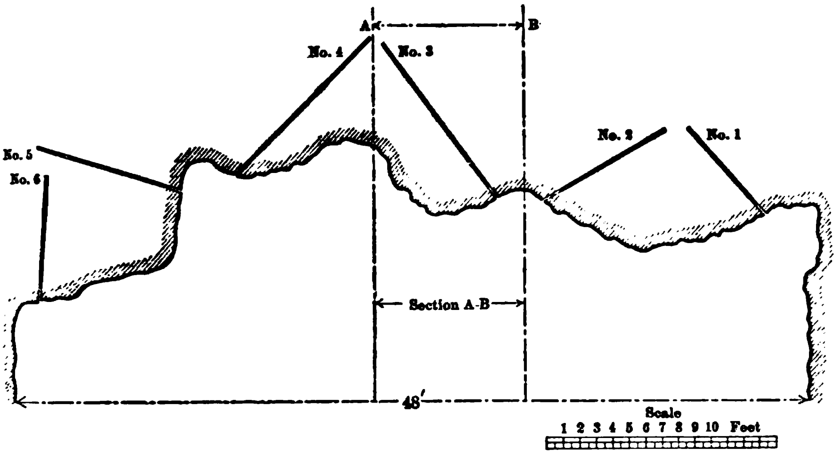

FIGURE 1.—Arrangement of drill holes in experiments in a limestone mine. Plan.

This necessitated the use of different quantities of explosives in the different working places. No. 6 electric detonators were used, and

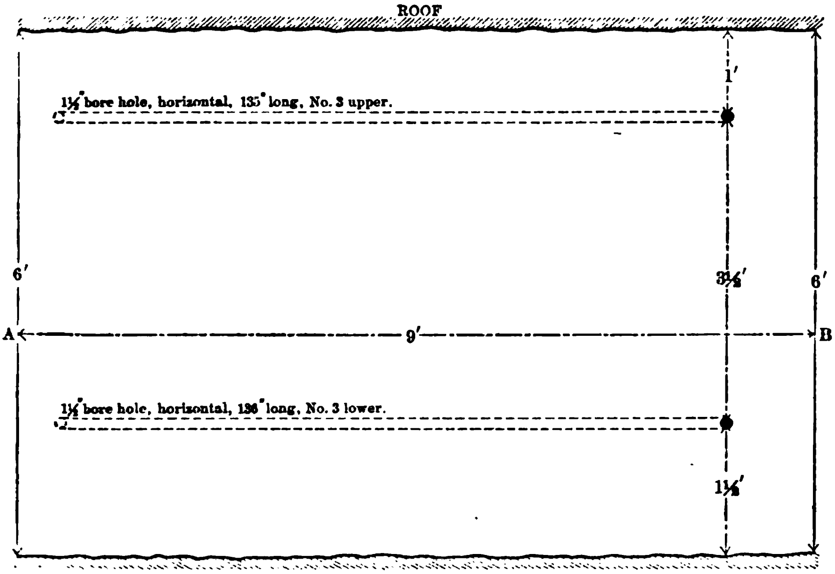
ROOF
1¼" bore hole, horizontal, 135" long, No. 3 upper.
1'
6'
3¾'
6'
A
9'
B
1¼" bore hole, horizontal, 136" long, No. 3 lower.
1¼'

FIGURE 2.—Arrangement of drill holes in experiments in a limestone mine. Position of holes in front elevation A–B of face.

the shots were connected in series and fired at one time. The results of the tests are tabulated on the page following.

Results of tests with different classes of explosives in a limestone mine at West Winfield, Pa.

Class and grade of explosive used.	Quantity of explosive used (pounds).	Location of blast.	Where sample was taken.	Time sample was taken.	Analyses of mine-atmosphere samples.[a]						
					CO_2	O_2	CO	N_2	H_2S	H_2	CH_4 and C_2H_4
40 per cent strength gelatin dynamite.	103.5	Room 5 off "A" cross entry.	At face of room near roof.	Immediately after firing blast.	2.67	19.53	0.25	77.44	0.0	0.11	0.0
				5 minutes after blast.	1.75	19.73	.12	78.34	.0	.06	.0
				10 minutes after blast.	.43	20.31	.10	79.11	.0	.05	.0
Do.	39.5	Room 1 off 4th crosscut.	...do...	Immediately after firing blast.	.25	20.38	.05	79.29	.0	.03	.0
				5 minutes after blast.	.15	20.70	.0	79.15	.0	.0	.0
				10 minutes after blast.	.13	20.54	.0	79.33	.0	.0	.0
New 40 per cent strength gelatin dynamite.	28.5	Room 10 off "B" crosscut.	...do...	Immediately after firing blast.	.37	20.43	.0	79.20	.0	.0	.0
				10 minutes after blast.	.10	20.80	.0	79.10	.0	.0	.0
40 per cent "straight" nitroglycerin dynamite.	22.0	"D" crosscut.	...do...	Immediately after firing blast.	1.65	20.40	.40	78.35	.0	.20	.0
				2 minutes after blast.	.27	20.45	.15	78.87	.0	.06	.0
				12 minutes after blast.	.08	20.80	.0	79.12	.0	.0	.0

[a] G. A. Burrell, analyst.

TESTS IN A ZINC MINE.

The second series of experiments was carried out in a zinc mine at Franklin Furnace, N. J. W. O. Snelling, consulting chemist of the bureau, cooperated in the tests. The headings in which the tests were made averaged about 5 feet in width and 7 feet in height. In driving these headings a "21-hole cut" was used (figs. 3 and 4). In such a cut the first shot hole *a*, is fired in the center of the face. It is known as a "burning" shot and is not intended to blast out any material but merely to form a crack in the middle of the face or so to disintegrate the rock that when the first round of shots, holes *b* and *c*, is fired the material will be blasted out. Holes *d* and *e* were not loaded. The method of loading and firing the second, third, and fourth rounds of shots is similar to that generally followed in metal mines.

The holes for the second round of shots were spaced as shown in figure 3, the holes for this round being designated *f*, *g*, *h*, and *i*; the holes for the third round of shots were spaced in accordance with those lettered *o*, *p*, *q*, *r*, *s*, *t*, and *u* in the figure, and the holes for the fourth round were spaced in accordance with those lettered *j*, *k*, *l*, *m*, and *n* in the figure. The depth of the holes, the number of cartridges of explosives used in each, the length of drill hole which they occupied, the length of drill hole occupied by the stemming, and the free portion of the drill hole (that portion of the drill hole that is in front of the stemming and not occupied—see fig. 4) for the third round of holes shot with the new 40 per cent strength gelatin dynamite are indicated in figures 3 and 4 and in the table following.

Details of tests of explosives in a zinc mine at Franklin Furnace, N. J.

Hole.[a]	Number of cartridges.	Depth of drill hole.	Explosive occupied—	Stemming occupied—	Free portion of drill hole.
		Inches.	*Inches.*	*Inches.*	*Inches.*
o	6	79	44½	3½	31
p	5	76	41	10	25
q	8	87	52	8	27
r	6	80	46	9	25
s	7	86	54	5	27
t	7	89	51	12	26
u	8	87	59	8	20

[a] See figure 3.

Attention is called to the comparatively small amounts of stemming used in front of the charge as compared with the large amounts of explosives used, although the charging was done by an experienced man and according to the usual practice in that mine. An investigation of the effect of stemming on the efficiency of explosives which is now in progress by the bureau[a] indicates that the amount of stemming used in these shots was not sufficient.

The results of the experiments in the zinc mine are shown below:

Results of tests with different classes of explosives in a zinc mine at Franklin Furnace, N. J.

Class and grade of explosive used.	Quantity of explosive used (pounds).	Location of blast.	Where sample was taken.	Time sample was taken.	Analyses of mine-atmosphere samples.[b]						
					CO_2	O_2	CO	N_2	H_2S	H_2	CH_4 and C_2H_4
New 40 per cent strength gelatin dynamite.	18.4	400-foot level, 500 crosscut east, third round of holes.	4 feet from face, 5 feet from floor.	2 minutes after firing blast.	1.80	20.20	0.0	78.00	0.0	0.00	0.00
	32.0	Same (4th round of holes).	...do......	.....do........	1.25	20.30	.0	78.45	.0	.00	.00
40 per cent strength ammonia dynamite.	25.6	450-foot level, 800 crosscut, third round of holes.	...do......	.....do........	.65	20.46	.05	78.84	.0	.00	.00
			..do......	.....do........	4.45	18.56	.09	76.90	.0	.00	.00
	12.3	Same (4th round of holes).	68 feet from face, 5 feet from floor.	3 minutes after firing blast.	.59	20.19	.00	79.27	.0	.00	.00
40 per cent "straight" nitroglycerin dynamite.	25.0	450-foot level, north heading, second round of holes.	4 feet from face, 5 feet from floor.	2 minutes after firing blast.	1.76	20.17	.11	77.92	.0	.04	.00
			35 feet from face, 5 feet from floor.	4 minutes after firing blast.	.98	20.50	.0	78.48	.0	.04	.00

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[a] See Technical Paper 17, Bureau of Mines.

[b] G. A. Burrell, analyst.

CONCLUSIONS.

The mine tests, although of small scope, confirmed, with a few exceptions, the tests made in the pressure gage. The odor of hydrogen sulphide was noticeable immediately after firing some of the explosives containing sulphur, but the chemical analyses of the mine-air samples failed to disclose the presence of an appreciable quantity of this gas. Several days intervened between the taking of the samples in the mine and the chemical examinations made of them, and it is possible that if minute quantities of hydrogen sulphide were collected in any of the samples, they were decomposed by standing so long. It is worthy of note that in all the tests the explosives were completely detonated and there was no formation of nitrogen oxides.

The results of the experiments indicate that all gelatin dynamites should be made with an oxygen excess sufficient to completely oxidize all combustible materials present, including the wrappers; furthermore, the tests show that when this class of explosive is properly and completely detonated the proportion of harmful gases evolved is reduced to a minimum. However, it should be remembered that proper conditions do not exist if there has been any chemical or physical change in the explosive or if it is fired under conditions that cause burning or incomplete detonation. When the explosive has aged to such an extent as to materially decrease its sensitiveness, when weak detonators are used, or when the explosive is used in a frozen or partly frozen condition, a greater quantity of poisonous gases is evolved.

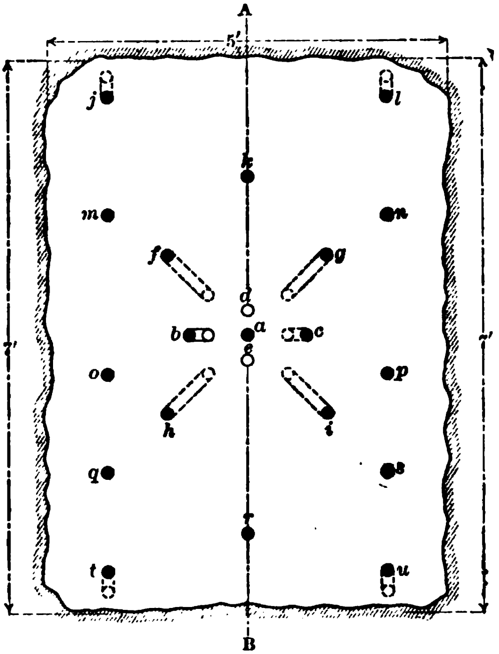

FIGURE 3.—Arrangement of drill holes in experiments in a zinc mine. Front view of face.

GASES EVOLVED IN THE BURNING OF EXPLOSIVES.

To determine the percentage of poisonous gases evolved when high explosives burn, a charge of 54½ grams of the "ordinary" 40 per cent strength gelatin dynamite, including paper wrapper, was ignited by an electric igniter in the pressure gage under atmospheric pressure. The gage was closed except that the indicator-connection hole was left open for the collection of samples of the gaseous products. The analysis of these products is given in the following tabulation:

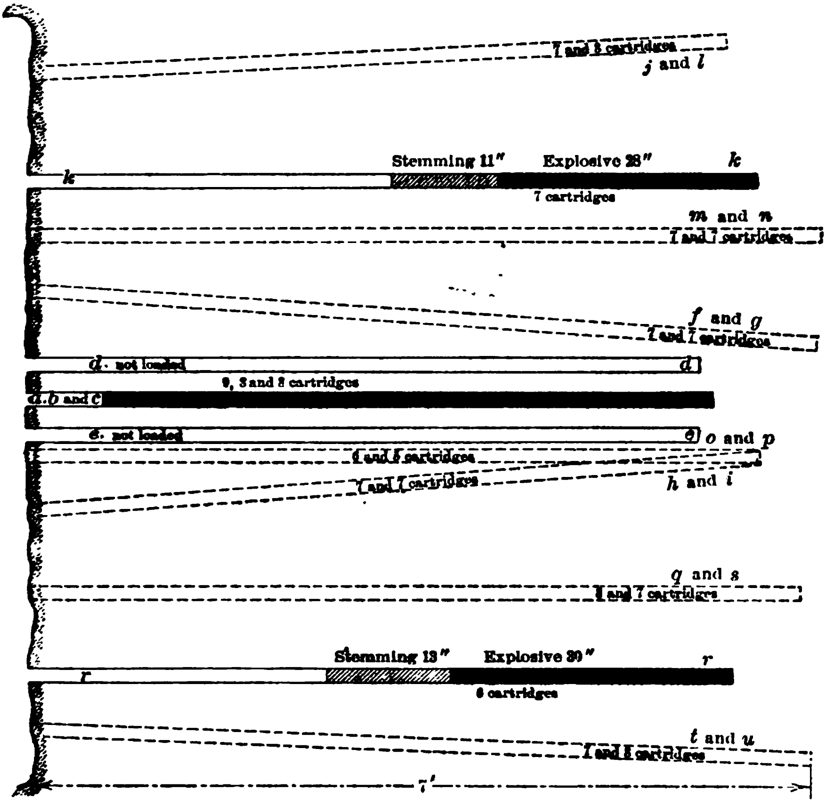

FIGURE 4.—Arrangement of drill holes in experiments in a zinc mine. Section through face.

Analysis of gaseous products of combustion.

[A. L. Hyde, analyst.]

Carbon dioxide	19.4
Oxygen	.0
Carbon monoxide	13.7
Nitric oxide (NO)	11.3
Hydrogen	.4
Methane	1.4
Nitrogen	53.2
Nitrogen peroxide (NO_2)	.6
	100.0

It is to be noted that the percentages of poisonous gases evolved, 13.7 per cent of carbon monoxide and 11.9 per cent of nitrogen oxides, show an increase of 18.5 per cent over the percentages from the same explosive when completely detonated in gage tests. It is reasonable to suppose that the results would be the same if the explosive burned and did not detonate under actual mining conditions in the blasting of rock and similar materials.

CHEMICALS PROPOSED FOR NEUTRALIZING POISONOUS GASES.

In order to neutralize or to prevent the formation of poisonous gases evolved on the detonation of explosives when used in blasting operations, the use of several compounds has been proposed. The compounds proposed consist of oxygen-carrying salts or of mixtures of alkaline carbonates or bicarbonates, camphor (gum), etc. They have been offered to the trade packed in cardboard cartridge shells weighing about 1 ounce each. It is claimed by the manufacturers of these compounds that if one cartridge thereof be placed in the back of a drill hole before loading a charge of 1½ pounds of 40 per cent dynamite, its action when the explosion occurs will prevent the formation of all poisonous gases or will neutralize them.

The use of compounds that have oxygen-carrying salts might offer some advantages with explosives deficient in oxygen. However, such compounds probably could not be used with explosives designed for use in coal mines. If the compounds entered into the explosive reaction and thus prevented the formation of carbon monoxide, the increased volume of carbon dioxide formed would probably be accompanied by a larger evolution of heat and the higher flame temperature might eliminate the safety features of the explosive.

Tests in coal mines have shown that coal drillings in a shot hole enter into the explosive reaction. Moreover, the gaseous products of blasts in coal contain, for any explosive, more carbon monoxide and less carbon dioxide than the products of explosion tests in metal gages.

The following tabulation gives the results of analyses of the gases produced from black blasting powder when fired under the usual conditions in a metal gage, and also under actual coal-mining conditions:

Results of analyses of gaseous products of explosion of black blasting powder.

Constituents.	Gage tests.[a]		Mine tests.[b]
	Cartridges without paper wrapper.	Cartridges with paper wrapper.	Cartridges with paper wrapper.
Carbon dioxide	49.7	44.9	19.2
Carbon monoxide	10.8	13.2	28.2
Oxygen	.0	.0	.0
Hydrogen	1.8	4.2	10.0
Methane	.6	.4	.4
Nitrogen	28.4	27.3	35.4
Hydrogen sulphide	8.7	10.0	6.8
	100.0	100.0	100.0

[a] A. L. Hyde, analyst.

[b] G. A. Burrell, analyst. The samples were taken from crevices caused by the explosion. As the crevice gases are diluted with air, the mine samples, for comparison with the gage-test results, were computed on an air-free basis; that is, the oxygen content was eliminated and a corresponding percentage of nitrogen (according to the proportion in normal air) was subtracted. Also, the proportion of methane distilled or pressed out of the coal was subtracted to make the methane percentage correspond to that of the gage samples.

The results tabulated indicate that any chemical containing sufficient oxygen, if associated with the explosive charge in the drill hole in a similar way, would tend to reduce the formation of carbon monoxide and, accordingly, minimize some of the poisonous gases formed. Obviously, if the chemical could be intimately associated with the ingredients of the explosive, a more complete reaction would result, but as this procedure is impracticable in loading charges of explosives and as the user of explosives would not know the exact amount to use with different brands of explosives, the value of using chemicals of this kind in mining operations is questionable.

It has been stated that explosives can be manufactured for tunneling and for metal mining that do not produce poisonous gases when completely detonated. Complete combustion can be assured if the manufacturers use a quantity of the oxygen-carrying salts sufficient to oxidize completely all the combustible ingredients of the explosives, including paper wrappers. Explosives so constituted would not require the use of auxiliary materials.

Compounds containing alkaline carbonates, bicarbonates, camphor (gum), etc., proposed for use in preventing the formation of poisonous gases are equally unsatisfactory. It has been pointed out that explosives on burning produce nitrogen oxides and that the presence of alkaline carbonates or bicarbonates may tend to neutralize to some extent the poisonous gases. However, as the nitrogen oxides are not formed when the explosives are completely detonated and as the complete detonation of explosives can be brought about by the use of a detonator of the proper kind, it is unnecessary to resort to the use of these compounds. When using compounds of this kind the miner has often been misled by the pleasant aromatic odor often noticeable in the working places after a blast. A series of tests with the compounds was undertaken to determine whether their use would render less noxious the gaseous products of an explosion of dynamite.

The compound used in the tests was a fine crystalline powder packed in a cardboard cartridge shell which was crimped at each end over a cardboard wad. The average weight of the ingredients of each cartridge was 13.6 grams, the cardboard cartridge shell or wrapper weighing 9.6 grams. The materials used were said to be ammonium carbonate, sodium bicarbonate, chloride of lime, and gum camphor. The result of a chemical analysis of the compound, as used, was as follows:

Results of analysis of a neutralizing compound.

[C. G. Storm, analyst.]

Moisture	4.01
Camphor gum	9.33
Sodium bicarbonate	14.62
Sodium chloride	9.30
Ammonium carbonate	42.88
Calcium carbonate	19.86
	100.00

It was evident that certain reactions had taken place after the compound had been made. The chlorine of the chloride of lime had been liberated and was combined as sodium chloride. There was evidence that other reactions had taken place, but they were not believed to be such as to have affected materially the value of the composition for the purpose intended. In the tests various mixtures of the compound and 40 per cent "straight" nitroglycerin dynamite were used. The prepared charges were fired by No. 6 electric detonators in a metal gage from which practically all of the air had been pumped by a vacuum pump. After the gases within the gage had cooled, their temperature and pressure were read, their weight in grams and their volume in liters being then computed. A differential sample of the gaseous products of combustion was procured by collecting the gas as it escaped through the gage valve. The percentage by volume of the gaseous products of combustion and the quantity in liters of each of the gases evolved are given in the following table in which, for convenience in reporting the results, the tests are designated A, B, C, D, E, and F.

Results of tests of mixtures of dynamite and a neutralizing compound.

Test designation.	Weight of original wrapper per 100 grams of explosive ingredient.	Weight of compound used, including cardboard wrapper.	Total weight of charge.	Gaseous products of combustion, per cent by volume.[a]					
				CO_2.	O_2.	CO.	H_2.	CH_4.	N_2.
	Grams.	*Grams.*	*Grams.*						
A	None.	None.	[b] 206.0	51.4	0.0	5.0	2.2	0.3	41.1
B	6.2	None.	[c] 212.4	27.3	.0	26.9	18.0	.4	27.4
C [d]	6.2	7.2	[c] 219.6	25.6	.0	28.2	18.9	.5	26.8
D [d]	6.2	23.8	[c] 236.2	20.7	.0	31.5	25.0	.7	22.1
E [e]	6.2	7.2	[c] 219.6	24.5	.0	28.5	20.4	.6	26.0
F [f]	6.2	[f] 4.2	[c] 217.1	28.2	.0	25.5	17.7	.4	28.2

COMPUTATIONS BASED ON THE ABOVE RESULTS OF TESTS.

Test designation.	Weight of gas.	Volume of gas.	Volume of the gaseous products of combustion.					
			CO_2.	O_2.	CO.	H_2.	CH_4.	N_2.
	Grams.	*Liters.*	*Liters.*	*Liters.*	*Liters.*	*Liters.*	*Liters.*	*Liters.*
A	88.4	55.6	28.6	0.0	2.8	1.2	0.2	22.9
B	107.4	87.0	23.8	.0	23.4	15.7	.3	23.8
C	111.1	91.7	23.5	.0	25.9	17.3	.5	24.6
D	124.0	112.2	23.2	.0	35.3	28.0	.8	24.8
E	108.2	91.3	22.4	.0	26.0	18.6	.5	23.7
F	108.8	87.4	24.6	.0	22.3	15.5	.3	24.6

[a] A. L. Hyde, analyst.

[b] Includes the 6-gram tinfoil wrapper.

[c] With the original paper wrapper weighing 12.4 grams.

[d] The cardboard wrapper of the compound was cut into small pieces and together with the compound was thoroughly mixed with the explosive ingredients.

[e] To simulate average mining conditions, 7.2 grams of the compound, including the cardboard wrapper, was placed at the end of the explosive charge opposite the end in which the electric detonator was placed.

[f] Made under the same conditions present in test E, except that the cardboard wrapper of the compound was replaced by a tinfoil wrapper weighing 0.5 gram.

Logical conclusions from the results of the tests are that compounds of this kind offer no advantage in preventing or neutralizing the poisonous gases evolved on the detonation of explosives; that the heavy cardboard wrapper used is responsible for an increase in the percentage of carbon monoxide formed, and that if such a compound is used as recommended by the manufacturer its use will produce a greater rather than a less amount of poisonous gases.

EXPLOSIVES FOR USE IN GASEOUS OR DUSTY COAL MINES.

PERMISSIBLE EXPLOSIVES.

Explosives suitable for use in gaseous or dusty coal mines differ greatly from those previously mentioned in this paper. In addition to possessing the requisite qualities of strength and efficiency in breaking down coal, they should be of such a composition as to produce, on explosion, a relatively short flame of relatively low temperature.

To accomplish this result, free water or an excess of carbon are added to some of the coal-mining explosives, and others contain flame-reducing salts. To determine whether an explosive is satisfactory requires careful testing. To carry out such tests the Bureau of Mines has installed at its Pittsburgh testing station suitable equipment, including a large steel cylinder or gallery which can be filled with fire damp or coal dust and air in any desired proportion.

Explosives that pass certain tests and that are used in accordance with the conditions prescribed by the bureau are called permissible explosives and are recommended for use in coal mines.

The underlying reasons why one explosive passes and another fails when tested in the presence of gas and dust have been investigated at the Pittsburgh testing station. The results of the researches, especially those on explosives that failed to pass the prescribed tests, have been reported to the manufacturers, who have in nearly all cases so changed and perfected their explosives that later when new explosives were submitted all the requirements of the bureau have been successfully met. The results of tests indicate that every explosive if fired in very large quantities will cause ignition of gas and coal-dust mixtures. An arbitrary charge, 1½ pounds, has been established as the quantity of explosive to be used in making tests, and all explosives in order to be placed on the permissible list must pass the gas-and-dust test with this charge. A charge of 1½ pounds per drill hole should never be exceeded in practice. In good mining practice the charge need not exceed 1 pound, an amount that provides a greater factor of safety.

In order to ignite inflammable gas and coal-dust mixtures a certain temperature, acting through a certain length of time, is required. Furthermore, the flame temperature of all explosives on detonation exceeds the ignition temperature of inflammable gas-and-dust mixtures, but fortunately the flame of the permissible explosives, when properly detonated, is of such short duration that the inflammable mixtures are not ignited. It is evident that any factor that increases the duration of the flame temperature of a permissible explosive, such as the use of a weak detonator or the use of any explosive in ways not in accordance with those prescribed by the Bureau of Mines, may increase the danger in its use.

Permissible explosives are now being used in every coal-mining State in the Union. In 1909 there was 8,592,000 pounds of permissible explosives used in this country. In 1910 the amount used reached 11,900,000 pounds, and in 1911 the amount aggregated 13,428,000 pounds.

EXPLOSIVES USED IN SUBMARINE OPERATIONS.

At the request of T. P. Roberts, assistant United States engineer, the explosives section of the bureau began an investigation to determine the cause of failures of certain shots in December, 1911, in connection with the blasting of rock in the bottom of the Monongahela River at Lock No. 1, Pittsburgh, Pa.

METHOD OF BLASTING FOLLOWED AT LOCK NO. 1, MONONGAHELA RIVER.

The procedure followed was found to be similar to that ordinarily employed in submarine excavating. A drill boat was moored over the rock by means of adjustable legs and by mooring lines attached to the shore, and the holes were drilled in the underlying rock, a hard shale, by 2¼-inch steel drills guided by long iron pipes 4 inches in diameter. On December 19, 1911, the depth of the water where the work was being conducted was 10 to 13 feet, depending on the elevation of the bottom of the river. At the time of the failures reported the stage of the river was lower. The sediment and drillings that accumulated in the 4-inch pipes during drilling were removed at intervals by means of an iron gooseneck pipe 1 inch in diameter. After the holes had been drilled to the required depth they were loaded with 40 per cent low-freezing dynamite by lowering charges through the 4-inch pipes. Three to five 1¼ by 8 inch cartridges were generally used in each hole; the last stick was made into a primer containing one No. 6 electric detonator with 12-foot wires. Tallow was used to seal the cartridges in order to prevent the absorption of water by the explosives. All of the splicing of the legs of the detonators to each other and to the leading wires was well insulated. After the holes, usually 13 for a blast, had been charged, the iron pipes were carefully removed and the wires connected in series. The drill boat was then floated downstream to a safe position and the leading wires were connected to a No. 3 push-down, two-pole firing machine. Before firing, the explosives and detonators remained for one-half to one hour in the water, the temperature of which at the time of inspection was 1° C. (34° F.).

It was stated that during the work of excavating, 286 holes had been fired and 5 failures had occurred, 2 in one set and 3 in another. The first failure occurred on December 6. A set of 13 holes had been loaded, but the seventh and tenth holes misfired when the blast was made. The charging had progressed from holes 1 to 13, and it was stated that the explosive in hole No. 1 was not in the water over 45 minutes. One of the electric detonators was recovered intact, and it was thought the misfire might have been due to an imperfection in the detonator wire, but when connected to and fired by the No. 3 firing machine it detonated completely. The other detonator was not recovered.

The second failure occurred on December 15, when a set of holes similar to those previously described was fired. In this instance holes 11, 12, and 13 misfired. All the detonators were recovered and only one failed to fire when retested. This detonator was delivered to the testing station for examination. The samples of 40 per cent low-freezing dynamite representing the last three shipments were also procured for examination and test purposes. It was noted at the time of inspection that the shot firer in operating the No. 3 firing machine used only one hand to push down the ratchet bar and did not push it down in that quick and forcible manner requisite for producing the maximum speed of the revolving armature.

TESTS OF ELECTRIC DETONATORS.

The first series of tests of electric detonators at the Pittsburgh testing station was made by connecting 30 No. 6 electric detonators in series and firing them with a No. 3 push-down two-pole firing machine. The rachet bar was pushed down with different degrees of speed. In the two tests made, simulating the method used at Lock No. 1, there were 10 misfires in the first trial and 11 in the second. Two other tests were then made by pushing the rachet bar down with both hands quickly and forcibly, especially during the last part of the stroke. In both trials all detonators were fired. As the amount of current generated by any firing machine of this type depends upon the speed of the revolving armature it is evident that the misfires at Lock No. 1 were partly due to the improper method followed in operating the No. 3 firing machine. These machines are so made as to store up the current during the stroke until just as the stroke is ended, when the entire current that has gathered is discharged through the leading wires.

It has been found from results of tests that the resistances of the platinum-wire bridges in certain detonators of the same grade and make vary from 0.7 to 1.0 ohm and that the electric detonators that misfire are usually those having low resistance. It has been generally considered that the loss of current that may occur by short-circuiting through wet ground or water is largely responsible for misfires when electric detonators are fired in series, but the tests made at the testing station indicate that the variation in the cross-sectional area of the platinum bridges within the detonators is a factor of greater importance. It can not be assumed with certainty, however, that a platinum bridge having a high resistance can be fired with less current than one having a low resistance, because with a given current the maximum temperature of a bridge depends upon its minimum cross-sectional area only; the resistance varies not only inversely as the cross-sectional area of the bridge, but also directly as its length. An inspection of several bridges disclosed the fact that the length of the bridge did vary slightly, usually because of the encroachment of the solder on the platinum bridge.

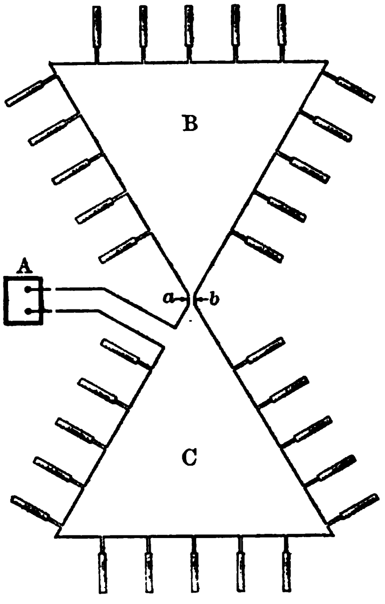

FIGURE 5.—Arrangement of electric detonators to determine whether a shunt of river water affected their detonation. A, firing machine; B, detonators of high resistance; C, detonators of low resistance; a, b, uninsulated wires.

Great care was necessary then in selecting detonators, and the assumption that the average detonator of high resistance would have a long bridge of relative small cross-sectional area, and the average detonator of low resistance would have a short bridge of relatively large cross-sectional area holds. For one test the resistance of 152 detonators was determined. Thirty of these were selected, 15 having the highest and 15 the lowest resistance. The resistances in ohms were as follows, the resistance of the detonators that failed being italicised: 0.90, 0.90, *0.90*, 0.91, 0.91, 0.91, 0.92, 0.92, *0.93*, 0.94, 0.95, 0.95, 0.95, 0.96, 0.96, and *0.72*, *0.73*, 0.76, *0.77*, 0.77, 0.78, 0.78, *0.79*, *0.79*, 0.79, 0.79, 0.80, 0.80, 0.80, 0.81.

The 30 detonators were connected in series (fig. 5) and in order that the effect of a possible loss of current through river water might be determined a shunt of river water at 15° C. (59° F.) was arranged between the two terminals (1 inch apart) of the 15 detonators having the high resistances (B, fig. 5.). An attempt was made to fire them with a No. 3 firing machine (A, fig. 5) operated at about half speed in order that the current passing through the bridges would fire some but not all of the detonators. If the conductivity of the water was great enough it was to be expected that the current passing through the 15 detonators of high resistance would not suffice to fire any of them; however, if the conductivity of the water was small enough it was to be expected that the following conditions would prevail:

1. That the average resistance of the detonators that failed would be less than that of those fired;
2. That the average resistance of the detonators of high resistance that failed would be less than that of those fired;
3. That the average resistance of the detonators of low resistance that failed would be less than that of those fired.

The actual results of the test may be expressed by detailing the averages corresponding to those mentioned above. These averages are presented below.

Average resistances of electric detonators tested.

	Ohms.
7 that failed	0.804
23 that fired	.868
2 of high resistance that failed	.915
13 of high resistance that fired	.929
5 of low resistance that failed	.760
10 of low resistance that fired	.788

Other similar tests confirmed in every particular the test outlined.

The results of these tests[a] showed that fewer failures occurred with the electric detonators having high resistance even when means were provided, as stated above, for introducing short-circuiting. It is unfortunate that the manufacturers of electric detonators can not supply platinum bridges having a more uniform cross-sectional area, but these unavoidable defects in bridges emphasize the importance of providing firing machines of adequate capacity and of operating them in such a manner that they will yield their maximum energy.

The electric detonator that failed on retest at Lock No. 1 was examined at the testing station by carefully opening the detonator in such a manner as to separate the sulphur plug from the copper capsule. The guncotton usually placed around the platinum bridge was slightly moist, a condition that would account for the failure of the fulminate charge to detonate. As previously stated, the three other detonators failed for the reason that when they were used the current passed through them was not strong enough to cause them to fire, probably because of their low resistance. One detonator was not recovered and this was the only failure that could in any way be attributed to the explosive.

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[a] A more extended study of the efficiency of electric detonators and firing machines is now in progress by the bureau.

TESTS OF EXPLOSIVES.

A physical and chemical examination was made of each of the three samples of dynamite submitted. They were found to be remarkably uniform in composition. The nitroglycerin content of the dynamite was equal to that usually offered for sale in this country as 40 per cent low-freezing dynamite. However, it is to be noted, that all of the samples contained about 5 per cent of sodium chloride, which substance is well known to cause the reduction of flame temperature on detonation of an explosive and hence causes a material reduction of the energy developed. The results of tests are given in the following tabulation:

Results of tests of three explosives[a] *used in submarine operations.*

PHYSICAL EXAMINATION.

Details observed.	Sample No. 1.	Sample No. 2.	Sample No. 3.
Length of cartridge, inches	8	8	8
Diameter of cartridge, inches	1¼	1¼	1¼
Weight, grams	203	198	203
Volume, cubic centimeters	163	157	158
Specific gravity	1.24	1.26	1.29
Redipped	No.	No.	No.
Spiral wrapped	Yes.	Yes.	Yes.
Color	Dark corn.	Dark corn.	Dark corn.
Consistency:			
Granulation--			
Structure	Fibrous and granular.	Fibrous and granular.	Fibrous and granular.
Size	Fine.	Fine.	Fine.
Liquidness	Dry.	Dry.	Dry.
Compactness	Very soft.	Very soft.	Very soft.
Cohesiveness	Slightly cohesive.	Slightly cohesive.	Slightly cohesive.
Weight of cartridge shell per 100 grams of explosive ingredient, grams	8.0	8.0	8.0

CHEMICAL ANALYSIS.

[A. L. Hyde, analyst.]

Moisture	2.78	2.27	1.88
Nitroglycerin	32.77	32.91	32.67
Nitrotoluene	5.98	6.39	6.07
Sodium nitrate	31.03	31.45	32.18
Wood pulp and crude fiber	9.88	9.83	9.30
Starch	6.17	6.31	5.78
Sodium chloride	5.03	4.92	5.77
Sugar	5.00	4.61	4.93
Calcium carbonate	1.36	1.31	1.42
	100.00	100.00	100.00

[a] 40 per cent strength low-freezing dynamites.

Because it was stated that the latest shipment of 40 per cent strength low-freezing dynamite received at Lock No. 1 was giving unsatisfactory results in that it seemingly did not develop the same energy as previous shipments, certain physical tests were made to determine the comparative strength of samples of the shipment. The results of the tests indicated that the samples were uniform in strength, but, as all the tests were made with fresh explosives taken from the original containers, it was decided to make certain efficiency tests with the samples after they had been submerged in water for different periods of time and under varying conditions. It was also deemed advisable to make comparative tests with other classes of dynamite at the same time in order to determine the type of explosive most suitable for the submarine blasting in question.

The selection of an explosive for submarine work is of special importance because of the severe moisture and temperature conditions under which it must be used, also because of the great expense incurred in preparing every blast, a consideration that makes any failure of importance. It has also been generally recognized that when used for blasting under water explosives produce less useful work than when used for excavating on land. This decrease is due to the reduction of the temperature of the products of combustion and to the confining effect of the water on the material to be blasted, an effect that more than counteracts the beneficial effects of the water stemming.

Four different classes of explosives were used in the comparative-efficiency tests. They are commercially known as 40 per cent strength low-freezing dynamite, 40 per cent "straight" nitroglycerin dynamite, 40 per cent strength ammonia dynamite, and 40 per cent strength gelatin dynamite. The physical examination of each explosive gave the following results:

Results of physical examination of four classes of explosives.

Details observed.	40 per cent strength low-freezing dynamite.	40 per cent "straight" nitroglycerin dynamite.	40 per cent strength ammonia dynamite.	40 per cent strength gelatin dynamite.
Length of cartridge, inches	8¼	8	8	7¾.
Diameter of cartridge, inches	1¼	1¼	1¼	1¼.
Average weight, grams	254	238	241	295.
Average volume, cubic centimeters	166	163	169	184.
Specific gravity	1.53	1.46	1.43	1.60.
Redipped	No	No	Yes	No.
Spiral wrapped	Yes	Yes	Yes	Yes.
Color	Dark corn	Fawn	Light café au lait.	Light café au lait
Consistency:				
Granulation—				
Structure	Fibrous and granular.	Fibrous	Granular	Gelatinous.
Size	Fine	Fine	Fine	Fine.
Liquidness	Wet	Dry	Dry	Wet.
Compactness	Soft	Soft	Soft	Soft.
Cohesiveness	Slightly cohesive.	Slightly cohesive.	Slightly cohesive.	Moderately cohesive.
Weight of cartridge shell per 100 grams of explosive ingredient, grams.	4.0	5.0	5.5	2.0

The results of the chemical analyses made disclosed the fact that these explosives were made under formulas somewhat similar to those of explosives of the same commercial rating generally offered for sale in this country. The analyses of these classes of explosives are given in the following tabulation:

Results of analyses of four classes of explosives.

Constituent.	40 per cent strength low-freezing dynamite.[a]	40 per cent "straight" nitroglycerin dynamite.[a]	40 per cent strength ammonia dynamite.[b]	40 per cent strength gelatin dynamite.[b]
Moisture	1.13	0.97	0.88	1.47
Nitroglycerin	27.56	39.19	21.60	30.70
Nitrocellulose				.88
Ammonium nitrate			18.86	
Nitrotoluene	10.13			
Sodium nitrate	51.54	49.53	46.04	54.27
Wood pulp	8.52	9.77	5.45	8.58
Sulphur			4.85	3.08
Zinc oxide			.88	1.02
Calcium carbonate	1.12	.54	1.44	
	100.00	100.00	100.00	100.00

[a] J. H. Hunter, analyst. [b] W. C. Cope, analyst.

TESTS OF EXPLOSIVES IN A FROZEN AND IN A THAWED CONDITION.

Tests were next made of explosives in a frozen and in a thawed condition.

The procedure in the first test was to submerge one cartridge of each class of explosive, in its original wrapper, under 1 foot of still water at a temperature of 1° C. (34° F.) for one hour. After taking the cartridges out of the water an attempt was made to fire each separately, unconfined, with a No. 6 electric detonator.

The cartridge of 40 per cent strength low-freezing dynamite was not frozen, but 2 inches of one end of the cartridge seemed to have absorbed an appreciable amount of water. When fired the detonation was seemingly complete.

The cartridge of 40 per cent "straight" nitroglycerin dynamite was found in a frozen condition. However, when fired complete detonation resulted. One-half inch of one end of this cartridge had absorbed water.

The cartridge of 40 per cent strength ammonia dynamite was found in a frozen condition but it detonated completely when fired. Two inches of one end of this cartridge had absorbed water.

The cartridge of 40 per cent strength gelatin dynamite was found in a frozen condition, but otherwise there was no change in its appearance. There had seemingly been no absorption of water. This cartridge failed to detonate when an attempt was made to fire it with a No. 6 detonator. All of the pieces of the cartridge that had been broken by the explosion of the detonator were recovered, and it was evident that not even a partial detonation of the cartridge had resulted.

Further tests were made with frozen cartridges under similar conditions, except that the cartridges were not submerged in water. They were taken from the magazine in a frozen condition and left for one hour at a temperature of −16° C. (3° F.).

Four cartridges each of 40 per cent "straight" nitroglycerin dynamite and of 40 per cent strength ammonia dynamite were fired separately, a complete detonation of each resulting.

Out of four trials, one failure to detonate occurred in tests of the 40 per cent strength low-freezing dynamite. With 40 per cent strength gelatin dynamite, failures to detonate occurred in each trial in each of four tests made.

Similar tests were then made by subjecting frozen cartridges of the four explosives to temperatures of 6° C. (43° F.) and of 8° C. (46° F.) for a few hours. Under these conditions the cartridges of 40 per cent strength gelatin dynamite were the only ones that failed to detonate. The results of the tests confirmed the previous results obtained with the gelatin dynamite. In no case was there even a partial detonation of the gelatin dynamite when attempts were made to fire it with a No. 6 electric detonator containing a 1-gram charge of fulminate composition.

Logical conclusions as a result of the tests of the explosives in a frozen and in a thawed condition are:

(1) That 40 per cent strength gelatin dynamite should never be used in blasting operations when the temperature is such as to cause the cartridges to freeze.

Attention is also called to the fact that some gelatin dynamites, after long storage in tropical countries, so lose their sensitiveness that they can not be detonated with the ordinary detonators generally used. This result is probably due to the fact that in the manufacture of gelatin dynamite the nitrocellulose used is not completely gelatinized, so that when the dynamite is stored in hot climates the process of gelatinization continues and, accordingly, the cartridges become harder and less sensitive.

(2) That, under the conditions that exist at Lock No. 1, the three other grades of dynamite are better adapted for use during the winter months.

However, it should be remembered that under actual mining conditions all of these grades have been known occasionally to detonate incompletely when used in a frozen condition, even when fired with No. 6 electric detonators. Therefore, it is preferable to use stronger electric detonators during the winter months.

Tests were also made to determine the disruptive effect developed by the four classes of dynamite in a frozen condition when fresh and when aged. The explosives were subjected to temperatures of 1° C. (34° F.) to −12° C. (10° F.), and tests were made by firing 100 grams of each explosive on lead blocks which were at room temperature, 18° C. (64° F.), the resulting compression being measured.

The tabulation following gives the results of small lead block tests made with each class of dynamite when used in a thawed, in a frozen, and in a frozen and aged condition. (See Pl. I.) The results of the tests herein reported, which were made in duplicate, checked within 5 per cent. No. 6 electric detonators, each containing a charge of 1 gram of fulminate composition, were used with the thawed explosives, but in order to increase the chances of detonation of the frozen explosives, No. 8 electric detonators, each containing a 2-gram charge of fulminate composition, were used. The compression resultant from the 40 per cent "straight" nitroglycerin dynamite, when thawed, is given a value of 100 per cent in the percentage strength column, and the results of tests with the other grades are computed on this basis in direct proportion.

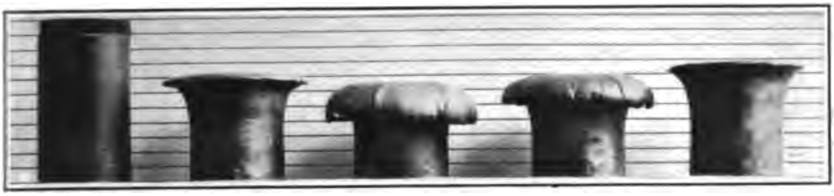
Results of small lead block tests with explosives in a thawed and in a frozen condition.

Physical condition of explosive.	Grade of electric detonator.	Class of explosive.							
		40 per cent strength low-freezing dynamite.		40 per cent "straight" nitroglycerin dynamite.		40 per cent strength ammonia dynamite.		40 per cent strength gelatin dynamite.	
		Average compression.	Disruptive effect.	Average compression.	Disruptive effect.	Average compression.	Disruptive effect.	Average compression.	Disruptive effect.
		Mm.	*Per ct.*	*Mm.*	*Per ct.*	*Mm.*	*Per ct.*	*Mm.*	*Per ct.*
Thawed, in a fresh condition.	No. 6	17.0	79.4	21.4	100.0	18.9	88.3	15.6	72.9
Frozen, in a fresh condition.	No. 8	12.5	58.4	Block ruptured.		18.6	86.9	14.9	69.6
Frozen, 2½ per cent of water added and well mixed	No. 8	9.0	42.1	17.4	81.3	[a]2.2	10.3	[a].9	4.2
Frozen, 5 per cent of water added and well mixed	No. 8	[a].2	0.9	[a]1.5	7.0	[a].9	4.2	[a].8	3.7

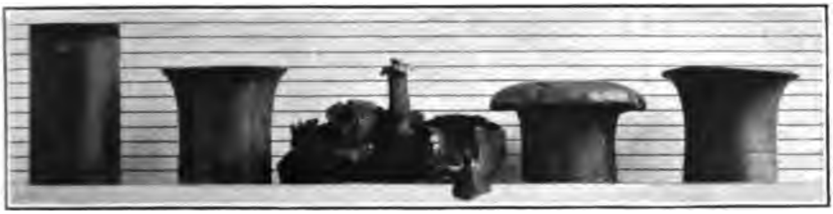
[a] Incomplete detonation.

In Plate I the effects of the several conditions are shown by *A*, *B*, *C*, and *D*; the effect of each explosive (low-freezing dynamite, "straight" nitroglycerin dynamite, ammonia dynamite, and gelatin dynamite) by blocks 1, 2, 3, and 4. An unused block, with steel cap in place, is shown at the left for comparison.

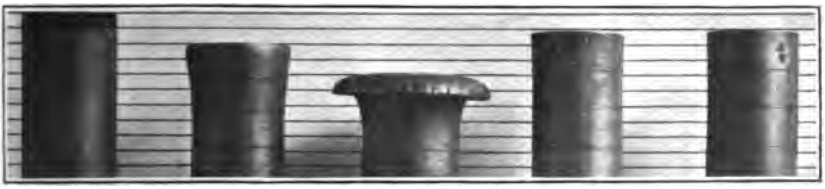
It is to be noted that 40 per cent strength low-freezing dynamite is the only class of explosive tested that showed a material loss in energy when fired in a frozen but fresh condition, when fired with No. 8 electric detonators (2-gram charge). It is also worthy of note that this is the first instance in the tests made that a detonation of frozen 40 per cent gelatin dynamite occurred. Attention is called, however, to the fact that comparatively small quantities of explosive in a fresh condition were used in the tests and also that



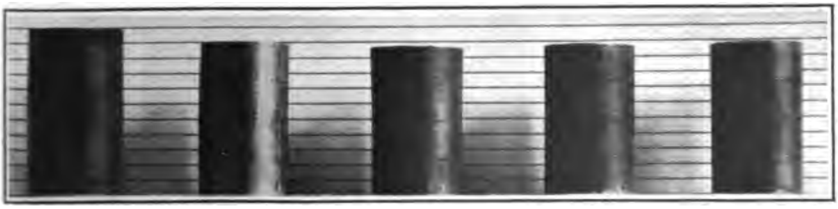
A. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES FRESHLY THAWED.



B. SMALL LEAD BLOCK TESTS OF FOUR FROZEN EXPLOSIVES IN A FRESH CONDITION.



C. SMALL LEAD BLOCK TESTS OF FOUR FROZEN EXPLOSIVES WITH 2½ PER CENT OF WATER ADDED.



D. SMALL LEAD BLOCK TESTS OF FOUR FROZEN EXPLOSIVES WITH 5 PER CENT OF WATER ADDED.

they received the full effect of a powerful detonator. A greater loss in efficiency results with all classes of explosives after they have aged and taken up water if tested in a frozen condition with detonators of less strength. Furthermore, when large quantities of frozen explosives are used in actual mining operations it has been generally recognized that the results are erratic if the explosives are fired with No. 6 electric detonators, and are especially so when detonators of a lower grade are used.

The disruptive force of the 40 per cent "straight" nitroglycerin dynamite when frozen but in a fresh condition was not less than that of the same dynamite in a thawed condition; this result was probably due to the stronger detonator used.

The addition of water to the different classes of explosives represents the effect of aging from absorption of moisture through improper storage, but the facility with which these different classes of explosives absorb any definite percentage of moisture during storage varies widely. The gelatin dynamite absorbs little and that only slightly into its surface. On the other hand, the ammonia dynamite, when its wrapper is broken or distorted, allows its hygroscopic ingredients to absorb moisture with great facility. The above differences being kept in mind, the results of the small lead block tests of explosives to which 2½ per cent of water has been added are properly interpreted as showing that those of the 40 per cent "straight" nitroglycerin dynamite are comparatively good, that those of the 40 per cent strength low-freezing dynamite are fair, that those of the 40 per cent strength ammonia dynamite are very poor, and that the results with the 40 per cent strength gelatin dynamite should not be interpreted as unfavorably as the test would seem to warrant. However, the results of tests with explosives to which 5 per cent of water has been added would probably indicate what may be expected from all classes of explosives stored under unfavorable conditions for a long period of time.

TESTS OF EXPLOSIVES IN A DRY AND IN A WET CONDITION.

A series of tests was undertaken to determine the energy of the four classes of explosives after they had been submerged in still water at a temperature of 17° C. (63° F.) for different periods of time.

It has been observed in practice that loss in efficiency results when explosives have been so submerged. The assumption has been that the resultant reduction of useful work is due to the fact that the nitroglycerin content of the explosives is to a certain extent replaced by water, and that certain of their ingredients, such as the nitrates, are soluble in water. The effect of water varies with the temperature, because the soluble salts of explosives are more readily dissolved in warm than in cold water. The style of wrapper, particularly as regards the sealing of the ends of the cartridge to prevent the absorption of moisture by the explosive ingredients, is of especial importance. Little difference was found in the wrappers used on the cartridges under test, except that the cartridges of 40 per cent strength ammonia dynamite had been redipped during their manufacture and accordingly offered a greater protection to the explosive ingredients within.

One series of tests with the ballistic pendulum was made to determine the comparative strength of the explosives (with No. 6 electric detonators) expressed as a propulsive effect. Small lead block tests were made to determine the comparative strength expressed as a disruptive effect. The ballistic pendulum[a] measures roughly the heaving force and the small lead blocks measure approximately the shattering force. The user of explosives, knowing which effect he desires to obtain, can use to advantage these results as a guide in selecting the explosive most suitable for his work.

In the tests, all of the cartridges were properly thawed before being submerged in water and, accordingly, were in a thawed condition when trials were made to determine their relative strength. The results of the tests are presented in the tabulations following. In the tabulations the results are referred to different series designated by letters, which are explained below.

SERIES A.

In the tests embraced in series A the explosives were tested as received.

SERIES B.

In the series B tests the explosives, in their original wrappers, were submerged for one hour under 1 foot of still water.

The average weight of the cartridges of 40 per cent strength low-freezing dynamite was 259 grams before soaking, and 270 grams after soaking, showing an increase in weight of 4.2 per cent. Each cartridge was soaked about 2 inches from the hand-crimped end of the cartridge shell.

The cartridges of 40 per cent "straight" nitroglycerin dynamite were affected in a similar way, except that the average increase in the weight of the cartridges was 2.4 per cent.

The cartridges of 40 per cent strength ammonia dynamite were soaked only one-fourth of an inch from the hand-crimped end of the cartridge shell, and the average increase in the weight of the cartridges was 1.1 per cent. It is worthy of note that this class of explosive, containing 19 per cent of ammonium nitrate, was little affected by the water test. This result was due to the protection afforded by the cartridge shells used, and shows the benefit of redipping the cartridges of explosives in melted paraffin.

The cartridges of 40 per cent strength gelatin dynamite showed little, if any, absorption of water. The average increase in the weight of the cartridges was 1.0 per cent. This increase was accounted for by the water that remained inside the cartridge and on the surface of the plastic ingredients.

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[a] See pp. 45-46.

SERIES C.

In the series C tests the explosives were submerged for one hour under 1 foot of still water but the cartridges were previously slit three times from end to end. This was done in order to represent unusually rough handling of the cartridges, and also to determine the effect of water on the cartridges of explosives when rammed into the drill holes.

The cartridges of 40 per cent strength low-freezing dynamite, of 40 per cent "straight" nitroglycerin dynamite, and of 40 per cent strength ammonia dynamite showed, respectively, an average loss in weight of 7.0, 8.7, and 1.1 per cent. All cartridges seemed to be saturated thoroughly and uniformly.

The cartridges of 40 per cent strength gelatin dynamite showed an average loss in weight of only 0.3 of 1 per cent. There was no visible change in the appearance of the explosive ingredients.

The loss in weight of the other classes of explosives is only partly indicated by the figures given, because there was a certain absorption of water which tends to increase their weights. It was observed during the tests that the cartridges at first gained weight by taking up water and then lost weight by the dissolving of the soluble ingredients.

SERIES D.

In the tests embraced in series D the cartridges, in their original wrappers, were submerged for eight and one-half hours under 1 foot of still water.

The cartridges of 40 per cent strength low-freezing dynamite, of 40 per cent "straight" nitroglycerin dynamite, of 40 per cent strength ammonia dynamite, and 40 per cent strength gelatin dynamite showed an average increase in weight of 0.0, 2.1, 8.1, and 4.2 per cent, respectively. All cartridges, except those of 40 per cent strength gelatin dynamite, were thoroughly and evenly saturated, and after they had been allowed to stand the usual time for draining at room temperature it was noted that the lower ends of the outside of the cartridge shells for a distance of 2 inches were covered with crystallized nitrates.

The cartridges of 40 per cent strength gelatin dynamite showed no change in the appearance of the cartridge shells or of the explosive ingredients.

SERIES E.

In the series E tests the cartridges, in their original wrappers, were submerged for eight and one-half hours under 1 foot of still water but the cartridges were previously slit three times from end to end.

The cartridges of 40 per cent strength low-freezing dynamite, 40 per cent "straight" nitroglycerin dynamite, 40 per cent strength ammonia dynamite, and 40 per cent strength gelatin dynamite showed an average loss in weight of 13.8, 16.0, 14.4, and 0.0 per cent, respectively. All of the cartridges, except those of 40 per cent strength gelatin dynamite, were completely saturated so that in taking them out of the water extreme care was required in order to retain the explosive ingredients in the cartridge shells. As in all previous tests, there was no visible change in the appearance of the cartridges of 40 per cent strength gelatin dynamite. In none of the tests was any liquid nitroglycerin found in any of the pails used, and only in the series E tests was any appreciable quantity of sediment found in the bottom of the pails.

BALLISTIC-PENDULUM TESTS.

The results of the ballistic-pendulum tests are tabulated below:

Results of ballistic-pendulum tests to determine the comparative propulsive effect of four explosives.

AMOUNTS OF EXPLOSIVES EQUIVALENT TO 227 GRAMS (½ POUND) OF STANDARD TESTING-STATION 40 PER CENT "STRAIGHT" NITROGLYCERIN DYNAMITE.

Series—	40 per cent strength low-freezing dynamite.	40 per cent "straight" nitroglycerin dynamite.	40 per cent strength ammonia dynamite.	40 per cent strength gelatin dynamite.
	Grams.	*Grams.*	*Grams.*	*Grams.*
A	229	234	241	283
B	233	240	247	288
C	239	235	258	282
D	235	241	279	281
E	[a] 1,009	[a] 857	[a] 848	279
COMPARATIVE STRENGTHS IN PERCENTAGES.[b]				
A	102	100	97	83
B	100	98	95	81
C	98	100	91	83
D	100	97	84	83
E	[a] 23	[a] 27	[a] 28	84

[a] One shot of each failed to explode.

[b] 40 per cent "straight" nitroglycerin dynamite in its ordinary condition is given a value of 100 per cent, the results of the tests being computed in direct proportion on this basis.

The results of the tests of the explosives in the form received (series A) show that the propulsive effect developed by the 40 per cent strength low-freezing, the 40 per cent "straight" nitroglycerin, and the 40 per cent strength ammonia dynamites were practically the same. It is evident, however, that the 40 per cent strength gelatin dynamite is not as efficient and will not develop the same heaving and pushing force as the other types of explosives.

In the series B tests (cartridges soaked in their original wrappers for one hour in still water) it is to be noted that there was no material loss in the propulsive effect of any of the explosives tested.

In the tests embraced in series C the cartridges that had been previously slit and then soaked for one hour in still water did not show any reduction in the propulsive effect from that obtained in the series B tests.

In the series D tests, embracing cartridges soaked in their original wrappers for eight and one-half hours in still water, the 40 per cent strength ammonia dynamite showed a loss in propulsive effect of 13 per cent. With the other explosive there was no perceptible reduction; the variations in results obtained are within the limits of error of the apparatus.

The greatest reduction of propulsive effect is shown in the results of the series E tests (cartridges slit from end to end and then submerged for eight and one-half hours under 1 foot of still water). The

40 per cent strength low-freezing dynamite, the 40 per cent "straight" nitroglycerin dynamite, and the 40 per cent strength ammonia dynamite showed losses in propulsive effect of 77, 73, and 72 per cent, respectively. The 40 per cent strength gelatin dynamite, as in all previous soaking tests, showed no loss in propulsive effect.

SMALL LEAD BLOCK TESTS.

The results of the tests with small lead blocks are given in the following tabulation:

Results of small lead-block tests to determine the comparative disruptive effect of explosives.

COMPRESSION OF LEAD BLOCKS.

Series—	40 per cent strength low-freezing dynamite.	40 per cent "straight" nitroglycerin dynamite.	40 per cent strength ammonia dynamite.	40 per cent strength gelatin dynamite.
	mm.	*mm.*	*mm.*	*mm.*
A	17.0	21.4	18.9	15.6
B	13.0	18.0	13.6	13.5
C	11.9	11.4	10.5	14.2
D	13.5	11.4	10.9	13.5
E	.0	.0	.0	12.6

COMPARATIVE STRENGTHS IN PERCENTAGES.[a]

A	79	100	88	73
B	61	84	64	63
C	56	53	49	66
D	63	53	51	63
E	0	0	0	59

[a] 40 per cent "straight" nitroglycerin dynamite in its ordinary condition is given a value of 100 per cent, the results of the tests being computed in direct proportion on this basis.

The appearance of the blocks after the tests is shown in Plate II, in which *A*, *B*, *C*, *D*, and *E* represent the corresponding series in the table of results, and 1, 2, 3, and 4 the blocks deformed by the action of low-freezing, "straight" nitroglycerin, ammonia, and gelatin dynamite, respectively.

It has often been observed that gelatin dynamite used unconfined rather than confined suffers a greater loss of efficiency than do the other three classes of "high" explosives. Consequently it is not surprising that the compression of the small lead blocks was less with this explosive than with the others tested. The observation mentioned is illustrated by the results of the tests, as follows:

The compression of the small lead block by the 40 per cent "straight" nitroglycerin dynamite fired in the usual way was 21.4 mm., but when the dynamite was confined in a can of water 6 inches high and 3½ inches in diameter the compression was 22.6 mm., a difference of 1.2 mm. On the other hand, the compression by 40 per cent strength gelatin dynamite, fired in the usual way, was 15.6 mm but when the dynamite was confined in a can of water 6 inches high and 3¼ inches in diameter the compression was 20.9 mm., a difference of 5.3 mm. The above results, however, must be interpreted with regard to the fact that the mechanical equivalent of the compression of lead increases per unit compression with an increase in the compression.

In the tests made with explosives as received (series A) the greatest disruptive effect was developed with 40 per cent "straight" nitroglycerin dynamite; accordingly, this class of explosive exerts the greatest shattering force.

When the cartridges in their original wrappers were soaked for one hour (series B) the 40 per cent "straight" nitroglycerin dynamite again showed the highest efficiency, but when the cartridges were slit and soaked for one hour this superiority did not exist.

It is evident from the results of the tests embraced in series C that 40 per cent strength gelatin dynamite, as compared with the other explosives tested, develops the greatest disruptive effect when the cartridges are slit and soaked for one hour, or when cartridges in their original wrappers are soaked for 8½ hours, as in the series D tests.

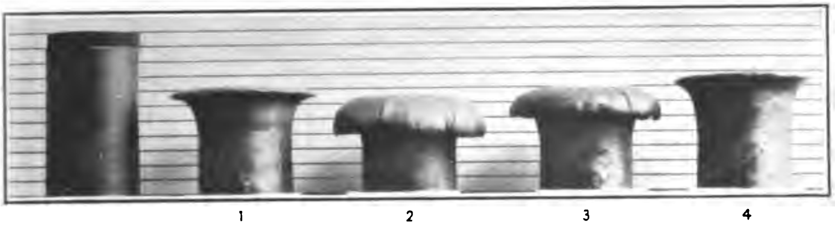
When the cartridges were slit and soaked 8½ hours (series E) the 40 per cent strength gelatin dynamite showed a loss in disruptive effect of 14 per cent. Under the same conditions the other classes of dynamites failed to detonate with No. 6 detonators, or at least sufficient energy was not developed to deform the lead blocks in any of the tests made.

PRACTICAL CONCLUSIONS.

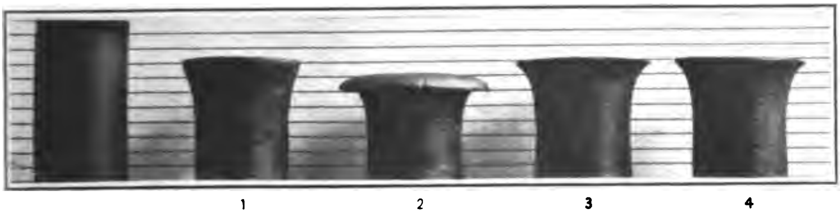
The procedure followed in connection with the work of blasting rock in the bottom of the Monongahela River at Lock No. 1 is in accordance with good mining practice. All explosives are carefully loaded in drill holes. They are not simply placed on the material to be blasted, a practice that, although sometimes followed in work of this kind, can not be considered economical.

In reference to the electric detonators used, it would seem that No. 6 electric detonators are satisfactory for the work, except during the winter months when the temperature of the water is low enough to cause the explosive charge to freeze. The factor of safety would be greater if No. 7 or No. 8 electric detonators were used.

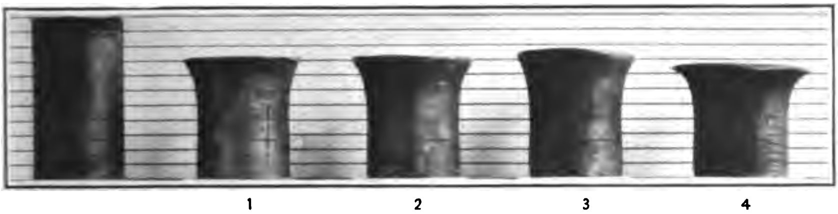
In view of the fact that out of 286 shots fired only one detonator failed to explode owing to the absorption of water, the use of the more expensive waterproof electric detonators is not warranted. However, attention is called to the fact that electric detonators similar to those now being used for wet work on the Isthmus of Panama can be purchased at the same cost as ordinary electric detonators. Such detonators contain a viscous compound between the sulphur plug



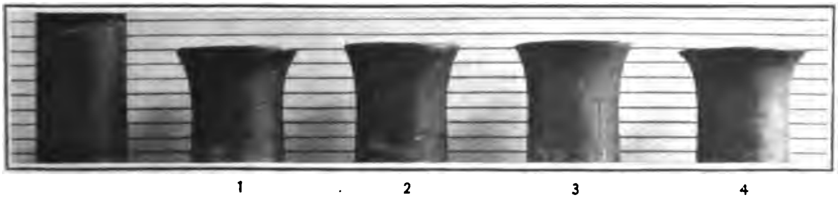
A. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES AS RECEIVED.



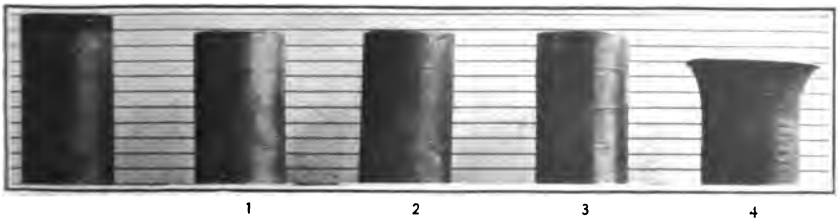
B. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES SOAKED IN WATER FOR ONE HOUR IN THEIR ORIGINAL WRAPPERS.



C. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES SLITTED AND SOAKED IN WATER FOR ONE HOUR.



D. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES AFTER SOAKING IN WATER FOR EIGHT AND ONE-HALF HOURS IN THEIR ORIGINAL WRAPPERS.



E. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES SLITTED AND SOAKED IN WATER FOR EIGHT AND ONE-HALF HOURS.

and the sulphur filling of the detonator. An electric detonator so manufactured withstands submersion in water for several hours.

In reference to the operation of the No. 3 firing machine, the recommendation is made that the ratchet bar be pushed down quickly and forcibly in order to obtain the maximum speed of the revolving armature. This manner of operation is necessary, because the cross-sectional area of the platinum bridges of electric detonators is not uniform, and as a result some detonators will fail if sufficient current is not produced to heat all the bridges to the proper temperature.

From the results of tests reported herein it is evident that 40 per cent "straight" nitroglycerin dynamite is the most suitable class of explosive for this submarine work.

If the work required longer intervals in the preparation of the shots, or if there were a material change in the character of the rock to be blasted, requiring explosives of different characteristics, the other classes of explosives might be used to advantage, subject to the conditions set forth in this publication.

TESTS OF EFFECT OF SUPERINCUMBENT MATERIAL.

As practically all primary blasting is done in material that is in some measure confined, it is reasonable to assume that this confining material will always offer resistance to the force of explosives and that the resistance will vary with the kind of material and the degree of confinement.

From what has been said before, it is obvious that the useful work that is obtained from explosives depends upon the class and grade of explosive, the quantity used, its physical condition, the method of application and the material blasted, but in submarine blasting there is another factor that is more liable to be overlooked than any of these although it is of great importance, namely, the effect of the superincumbent material.

In order to illustrate the importance of this factor, tests on small lead blocks and on a high grade of limestone were made, all conditions being the same except the character of the superincumbent material. In one case the quantity of explosive used was also varied.

The equipment used in the small lead block tests[a] is shown in figure 6. In addition to the regular small lead block equipment, cylinders containing water were used as shown in the figure. In one case only the charge of explosive was immersed in a cylinder of water, which in turn rested on the steel plate on top of the lead block. In the other case the explosive, the steel plate, and the lead block were all immersed in the water. With the explosive only immersed, the compression due to explosion was 17.8 mm. With the explosive, the steel plate, and the block all immersed, the compression was 13.0 mm. In each of these tests 100 grams of 40 per cent strength gelatin dynamite was used and the lesser compression was a result of the confining effect of the water surrounding the small lead block.

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[a] See also pp. 35–36.

"Adobe shots" were then made on two high-grade limestone blocks cut from the same large block and weighing 215 and 203 pounds (see *a* and *c*, Pl. III, *A*). Each block was approximately a cube, measuring 12½ by 12½ by 13 inches. The heavier block was selected for tests in the air. It was laid on two 6 by 6 inch timbers, and on the center of the top side a 50-gram 1¼-inch cartridge of the 40 per cent strength low-freezing dynamite was placed. A No. 6 electric detonator was inserted in the cartridge and laid parallel to the vertical bedding planes of the block. The charge was then covered with a 35-pound mud cap consisting of 30 pounds of dry fire clay mixed with 5 pounds of water (see *c*, Pl. III, *A*) and fired. The block was not shattered on top, but pieces were split off around the sides (see *b*, Pl. III, *B*). The other block was then immersed in a barrel of water having a temperature of 70° F. The water was 32 inches deep, there being 13¼ inches of water above the block. The charge was the same as in the previous trial except that no mud cap was used, and the charge was coated with paraffin in order to protect it from absorbing water. On firing no apparent damage was done to the block and no cracks were visible. This trial was then repeated on the same block immersed in water with a charge of 100 grams (see *a*, Pl. III, *B*). This greater charge did not break up the block as much as did the 50-gram charge when the block was in air only. The following tabulation shows comparative results:

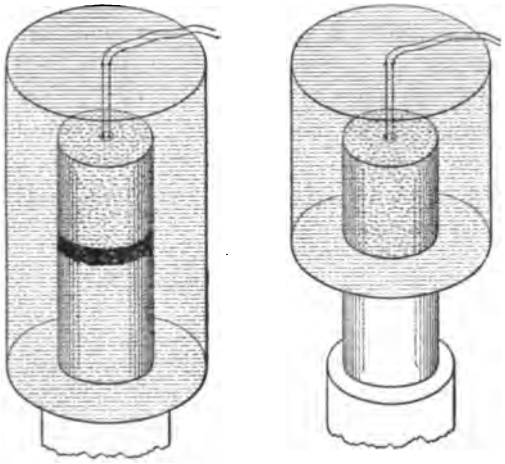
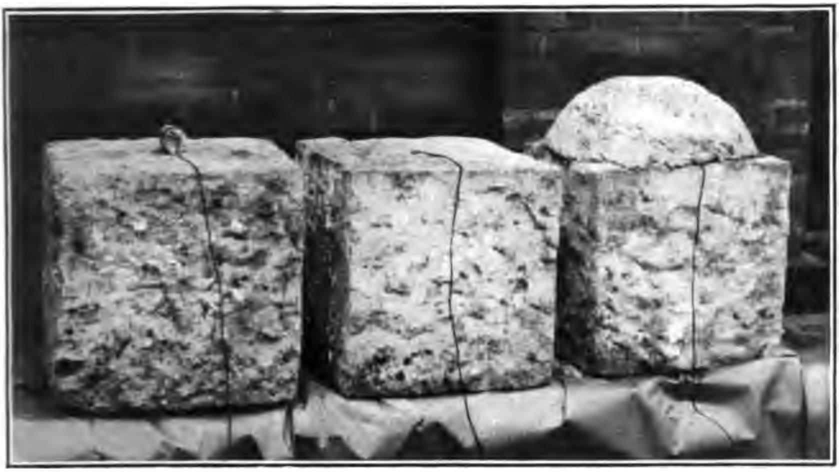


FIGURE 6.—Equipment used in tests to show the effect of surrounding medium on compression of small lead blocks by an explosive.

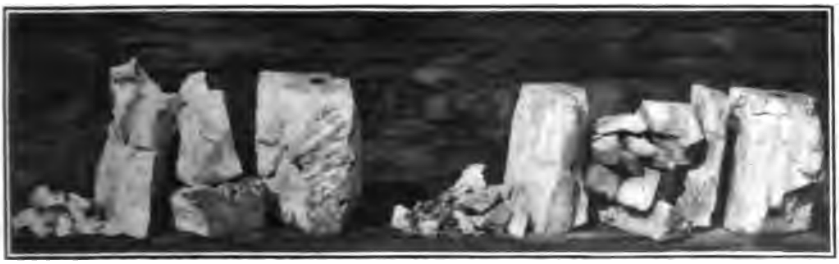
Comparative results of adobe shots on limestone blocks.

Condition of block.	Quantity of explosive used.	Weight of block.	Weight of largest piece.	Number of pieces over 3 inches in diameter.	Average weight of these pieces.	Total weight of small pieces.
	Grams.	*Pounds.*	*Pounds.*		*Pounds.*	*Pounds.*
In air	50	215	82	13	15.5	11
In water	[a] 100	203	104	8	24.6	5

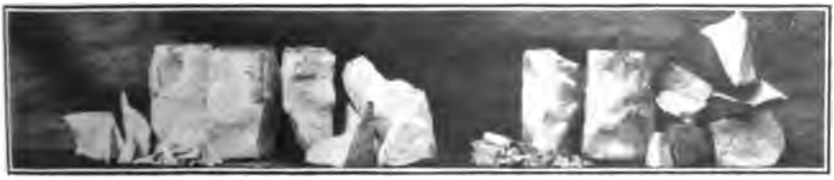
[a] After firing a 50-gram charge.



A. LIMESTONE BLOCKS BEFORE TESTS: *a*, BLOCK AND CHARGE BEFORE PUTTING ON MUD CAP FOR ADOBE TEST; *b*, BLOCK DRILLED AND CHARGED FOR BLOCK-HOLE TEST; *c*, BLOCK AND CHARGE AFTER PUTTING ON MUD CAP FOR ADOBE TEST.



B. RESULTS OF ADOBE TESTS: *a*, WITH BLOCK IMMERSED IN WATER, CHARGE, 100 GRAMS OF 40 PER CENT STRENGTH LOW-FREEZING DYNAMITE; *b*, WITH BLOCK IN AIR, CHARGE, 50 GRAMS OF SAME EXPLOSIVE.



C. RESULTS OF BLOCK-HOLE TESTS: *a*, WITH BLOCK IMMERSED IN WATER, CHARGE, 5 GRAMS OF 40 PER CENT STRENGTH LOW-FREEZING DYNAMITE; *b*, WITH BLOCK IN AIR, CHARGE, 5 GRAMS OF SAME EXPLOSIVE.

Other similar tests confirmed in every particular these tests, and again the confining effect of the surrounding material was shown. The above experimental proof is presented as a confirmation of practical experience that submarine blasting requires larger charges to disrupt a given amount of material than open work on similar materials.

Block-hole tests were made on two similar high-grade limestone blocks cut from the same large block and weighing 198 and 205 pounds. A hole 1 inch in diameter and 6 inches deep was drilled from the center of one side to the center of the block. (See *b*, Pl. III, *A*.) Each was charged with 5 grams of the 40 per cent strength low-freezing dynamite. A No. 6 electric detonator was used. The bore hole was filled with water in each case. The 198-pound block was fired in air (see *b*, Pl. III, *C*) and the 205-pound block was suspended in a barrel of water in the same manner as in the previous tests. Both blocks were broken (see *a*, Pl. III, *C*). The following tabulation shows the confining effect of the surrounding water:

Comparative results of block-hole tests with limestone blocks.

Condition of block.	Quantity of explosive used.	Weight of block.	Weight of largest piece.	Number of pieces over 2 inches in diameter.	Average weight of pieces over 2 inches in diameter.	Total weight of small pieces.
	Grams.	*Pounds.*	*Pounds.*		*Pounds.*	*Pounds.*
In air	5	198	52	15	12.7	7
In water	5	205	59	11	18.2	5

Incidently the tests with the high-grade limestone blocks show the superiority of the block-hole method of shooting as compared with adobe shooting, even though the mud cap in the abode shooting be very large.

DETERMINATION OF THE RELATIVE ENERGY AND EFFICIENCY OF EXPLOSIVES.[a]

It is evident that in hard-rock blasting operations in which a shattering effect is desired, the explosive reaction should be quick and explosives should be selected having a high rate of detonation. Likewise, for work in soft and friable ground an explosive should be selected that develops gases at a slow rate, in order that the pressure exerted will be more prolonged. In medium hard rock one might expect that an explosive having an intermediate rate would be most suitable, but such is not always the case. The lack of uniformity in rocks and the fact that a perfectly homogeneous mass or bed rarely exists are important considerations in blasting. In the Middle West there are fairly uniform limestone beds 12 to 14 feet thick in which quarry operations are being conducted. In one of these quarries visited by the writers, stone was being produced in one part of the quarry at a cost of 6 cents per ton for the explosives used. An explosive having a low rate of detonation gave satisfactory results there. In another part of the same quarry a different type of explosive having a much higher rate of detonation was found necessary in order to produce stone at the same cost, because local irregularities, such as clay "slips" and bedding cracks were more pronounced in that part of the quarry. Practical experience had shown that an explosive that develops its gases at a slow rate loses much of its energy through the escape of the evolved gases along the clay "slips," its efficiency being thus reduced.

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[a] For detailed descriptions of methods and apparatus used at the Pittsburgh experiment station for testing explosives, see Bull. 15, Bureau of Mines, Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe, 1912. 197 pp., 7 pls.

After a suitable class of explosive has been selected, it is necessary to determine the grade or strength of the explosive that is best adapted to the proposed work and that produces most economical results. It is well known that the potential energy of an explosive can be computed by measuring in a calorimeter the heat evolved on explosion. The potential energy thus obtained represents the maximum work that an explosive can theoretically accomplish. But as the useful work resulting from the use of explosives is a small percentage of the theoretical maximum, and varies considerably with the different classes of explosives, knowledge of the potential energy of explosives is of little value to the engineer in selecting a suitable explosive. For example, blasting gelatin, which is considered, on account of its high potential energy, the most powerful blasting agent known and hence the ideal explosive, has seldom given satisfactory or economical results in practice in this country. This is probably because the physical character of blasting gelatin is such that rapid detonation is not obtained with the means or devices ordinarily used in this country for detonating explosives.

It has been impossible to devise a single piece of apparatus for measuring both the disruptive and the propulsive effects produced by explosives. The apparatus used at the Pittsburgh testing station for determining these factors, which approximates the determination of the relative strength of explosives, is briefly described below, a tabulation of the results of tests made with different explosives being presented.

MEASUREMENT OF POTENTIAL ENERGY.

The apparatus used at the Pittsburgh experiment station for measuring the potential energy of explosives is the calorimeter.

CALORIMETER.

The construction of the explosives calorimeter is similar to that of the bomb calorimeters used for determining the heating value of fuels The reacting bodies are exploded in a bomb enveloped by a mass of water of known weight, and the increase in temperature of the water is measured with great precision. The bomb is made large and strong so that it may withstand the tremendous pressures resulting from the explosion. It is air-tight and practically all of the air it contains is pumped out by means of a rotary pump, before the charge is placed within it.

The bomb has a capacity of 30 liters and weighs 158 pounds. It is provided with a cover through which the charge may be placed, a valve through which the air may be pumped, and an insulated plug for carrying the electric current to the detonator placed in the charge. The charge used is 100 grams. No oxidizing material other than that supplied by the explosive itself is used. The water in which the bomb is submerged weighs 182 pounds. The rise in temperature of this water after the explosion of a charge is measured by a thermometer reading to thousandths of a degree Centigrade. Each result herein reported is the average of two tests agreeing within 5 per cent.

MEASUREMENT OF DISRUPTIVE EFFECT.

The devices used to measure approximately the disruptive effect of explosives, which bears a close relation to the percussive or shattering force, are the rate of detonation apparatus, Trauzl lead blocks, and small lead blocks.

METTEGANG RECORDER.

The rate of detonation apparatus comprises a Mettegang recorder and a covered pit in which the charge made up into a cartridge file is placed previous to the test.

The Mettegang recorder consists of a soot-covered bronze drum, pointed platinum terminals, tooth gear, and measuring adjustment, electric motor, vibration tachometer, and induction coils having primaries without iron cores. The drum is 500 millimeters in circumference and may be driven at any speed up to 105 revolutions per second. One edge of the drum is provided with 500 teeth, the same number as there are millimeters in the circumference. An endless screw engages these teeth and a pointer on this screw moves on a dial. Four platinum terminals are held by a nonconducting arm which may be moved so that the points are any desired distance from the drum. Each point is in series with a secondary coil, the other terminal of which is grounded to the drum through the base of the machine. Each primary coil is in series with ten 16-candlepower lamps and a copper wire running through one end of the cartridge file. The current used in the primary circuit has a potential of 220 volts. The vibration tachometer is connected to an auxiliary shaft, which engages the main shaft by gears, thus preventing any irregularity in speed due to slipping. The points of the drum are focussed on the cross hairs of a filar eyepiece which, with the endless screw, provides an exact means of measuring the distance between the two points.

The pit in which the cartridge file is suspended is 16 feet in diameter and 11 feet deep, and is closed at the top by means of a heavy reinforced concrete cover. A manhole in this cover provides entrance to the interior.

Each rate-of-detonation result herein reported is the average of two trials agreeing within 5 per cent. The determination was made on a cartridge file of explosive 1¼ inches in diameter and 1 meter in length, inclosed in a galvanized sheet-iron tube 42 inches long and 1½ inches in internal diameter. Copper wires leading from the Mettegang recorder were passed through the cartridge file 1 meter apart, the cartridge file was exploded, and from the time interval between the breaking of the wires, as shown by the recorder, was computed the rate of detonation.

The rate of burning of black blasting powder was determined by placing it in a hydraulic pipe having an inside diameter of 1½ inches. Each end of the pipe was filled with plaster of paris, the plaster extending for 4 inches at one end and for 1 inch at the other end. The charge was fired by means of an electric igniter. The time interval was determined by the Mettegang recorder.

DETONATING FUSE (CORDEAU DETONANT).

A unique method for determining the rate of detonation of explosives by means of detonating fuse (cordeau detonant), known as the Dautriche method,[a] is as follows:

A cartridge of explosive or an explosive file is suspended freely in the air, and at two points within the cartridge or file at a known distance apart are placed two detonators into each of which is previously crimped one end of a continuous detonating fuse, usually about 1 yard long. This fuse is bent so as to lie on a lead plate ½ by 3 by 15 inches in such a way that its middle point is directly over a previously marked position on the plate. The detonation of the cartridge of explosive detonates the detonators, and these in turn detonate an end of the detonating fuse. The point on the lead plate at which the detonations in the fuse meet is easily determined. The fuse has a known rate of detonation and from this, and the distance between the mark showing the middle point of the detonating fuse and the point on the lead plate at which the detonations meet, may easily be computed the rate of detonation of the explosive. The detonating fuse, known as "cordeau detonant," is made in diameters of 4 mm. and 6 mm., costs about 10 to 15 cents per yard, and may now be procured in this country. A few tests have been made with it at the testing station of the Bureau of Mines. The results obtained were fairly uniform and compared favorably with the results obtained with a Mettegang recorder as heretofore described.

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[a] Comey, A. M., Study of the velocity of detonation: 7th Inter. Cong. App. Chem., Sec. IIIb, p. 28.

TRAUZL LEAD BLOCKS.

The Trauzl lead-block test was conducted in the manner approved by the Fifth International Congress of Applied Chemistry. A cylindrical block of desilverized lead 200 millimeters in diameter and 200 millimeters in height, with an axial bore hole, 25 millimeters in diameter and 125 millimeters deep, was used. A charge of 10 grams of explosive was tamped with dry sand to the mouth of the bore hole and fired. No effort was made to confine the explosive further by means of plates and a yoke. The expansion of the bore hole was determined in cubic centimeters by measuring the volume of the bore hole with water before and after firing. Each result herein reported is the average of two tests agreeing within 5 per cent.

SMALL LEAD BLOCKS.

The small lead blocks are cylindrical in shape, 2½ inches long, and 1½ inches in diameter. Each block is inclosed in a piece of paper in such a way that a shell in which to place the charge is formed above the block. An annealed steel disk 1½ inches in diameter and one-fourth inch high is placed on top of the block. The block is placed on a firm horizontal base previous to firing the charge. A 50-gram charge of normal specific gravity is used in these tests. The electric detonator is centrally placed in the top of the charge. Compression of the lead block is determined in millimeters from its height before and after the explosion of the charge. Each result herein reported is the average of two tests agreeing within 5 per cent. This test is not suitable for use with black blasting powder as it provides little confinement for the charge.

The results of tests made to determine the disruptive effect of the various classes of explosives, as measured by the rate-of-detonation apparatus, Trauzl lead blocks, and small lead blocks, is given in the accompanying tabulation. The strength of 40 per cent nitroglycerin dynamite is taken as 100 per cent and the values for other grades are computed on this basis.

Results of tests of the disruptive effect of explosives.

Class and grade of explosive.	Diameter of cartridge (inches).	Number of electric detonator used.	Specific gravity of cartridge.	Rate of detonation.			Trauzl blocks.		Small lead blocks.	
				Meters per second.	Feet per second.	Percentage strength.	Expansion (c. c.).	Percentage strength.	Compression (mm.).	Percentage strength.
30 per cent "straight" nitroglycerin dynamite	1¼	6	1.31	4,548	14,920	95.3	196	73.4	17.3	83.6
40 per cent "straight" nitroglycerin dynamite	1¼	6	1.24	4,772	15,650	100.0	267	100.0	20.7	100.0
50 per cent "straight" nitroglycerin dynamite	1¼	6	1.38	5,748	18,850	120.5	281	105.2	21.1	101.9
60 per cent "straight" nitroglycerin dynamite	1¼	6	1.37	6,246	20,490	130.9	321	120.2	22.4	108.2
60 per cent strength low-freezing dynamite	1¼	6	1.14	5,072	16,640	106.3	246	92.1	17.0	82.1
40 per cent strength ammonia dynamite	1¼	6	1.57	3,157	10,350	66.2	202	75.7	12.8	61.8
40 per cent strength gelatin dynamite	1¼	6	1.65	4,943	16,210	103.6	195	73.0	12.1	58.5
5 per cent granulated nitroglycerin powder	1¼	[a]6	1.21	1,018	3,340	21.3	58	21.7	4.5	21.7
Black blasting powder	1¼	(b)	1.25	469	1,540	9.8	28	10.5	0.0	0.0

[a] A primer of 40 per cent "straight" nitroglycerin dynamite, representing 10 per cent by weight of the charge, was used in all the tests with this powder except those with the Trauzl lead blocks, and the energy produced by the primer is not included, except in the small lead-block tests.

[b] Black-powder igniter used.

MEASUREMENT OF PROPULSIVE EFFECT.

The apparatus used to measure approximately the propulsive effect of explosives, which corresponds closely to their heaving or pushing force, are the Bichel pressure gages and the ballistic pendulum.

BICHEL PRESSURE GAGES.

The pressure exerted by explosives is determined by means of the Bichel pressure gages. The test determines the theoretical maximum pressure developed by an explosive in its own volume after the elimination of the cooling influence of the surface of a gage.

The gages comprise two stout steel cylinders that may be made air-tight, each having an insulated plug for providing a means of igniting the charge, an air pump and proper connections for exhausting the air in either cylinder to an absolute pressure of 10 mm. of mercury, a valve by means of which this air pump can be isolated from the cylinder, and an indicator mechanism, the drum of which may be driven by a motor at a known speed. The cover of each cylinder is a heavy piece of steel held in place by 12 heavy stud bolts and an iron yoke. The piston of the indicator has a diameter of 0.3937 cm. and is resisted by one of several spiral springs of different strength. The particular one used is determined by the character of the explosive tested. The graphic record of the pressure developed within the cylinder is recorded on a paper placed on the circumference of the indicator drum. One of the cylinders has a capacity of 15 liters. The other cylinder is similar to the 15-liter cylinder in all particulars except that its capacity is 20 liters. In it, however, one or three steel cylinders are placed to reduce the capacity to 15 liters. The 15-liter cylinder has a cooling surface of 3,914 sq. cm. The 20-liter cylinder has a cooling surface, when the one large steel cylinder is in place, of 6,555 sq. cm., or, when the three smaller steel cylinders are in place, of 7,624 sq. cm. The charge of explosive used is 200 grams plus the weight of the paper wrapper. The weight of the wrapper bears the same relation to the weight of the explosive used in the test that it bears to the weight of the explosive in the original cartridge. Each result is the computed pressure in own volume as determined by the formula $M=\frac{VPS}{W}$, in which V represents the volume of the gage, which is always 15,000 cubic centimeters; S, specific gravity of the cartridge, and W, the weight in grams of the charge used in the test. It is important to observe the direct effect that the specific gravity has on the computed pressure in own volume, because any increase in the specific gravity gives a corresponding increase in the computed pressure in own volume. This relation is illustrated in the case of the 30 per cent "straight" nitroglycerin dynamite in the table on page 47.

P is determined by means of the formula $P=1.911A+0.5B-1.411C$, in which P represents the pressure with elimination of cooling surface and probable error; A, pressure developed with cooling surface of 3,914 sq. cm.; B the pressure developed with cooling surface of 6,555 sq. cm.; and C the pressure developed with cooling surface of 7,624 sq. cm. This formula expresses the geometrical relation obtained by platting the average pressure developed in two tests, agreeing within 5 per cent for each cooling surface, against the area of the cooling surface, the line drawn through the three points being extended to the ordinate of zero cooling surface. By platting the pressures against the cooling surfaces the effects of the cooling surfaces are eliminated.

BALLISTIC PENDULUM.

The ballistic pendulum is used to measure the deflective force of explosives. The apparatus consists of a 12.2-inch mortar suspended as a pendulum from a beam having knife edges, supported by two massive concrete piers, a cannon mounted on a truck, a track upon which the truck rests, and an automatic recording device. The mortar weighs 31,600 pounds and hangs in two U-shaped rods. The rods pass through and are held by two cast-steel saddles which fit over the supported beam. The radius of the swing measured from the point of the knife edges to the center of the trunnions is 89¾ inches.

The cannon is 24 inches in diameter and 36 inches long, and its axial bore is 2¼ inches in diameter and 21½ inches deep.

The swing of the mortar is measured by an automatic recording device which consists of a movable scale and a vernier set on a metal base fastened to a concrete footing. The scale is actuated by a long rod set in guides which bears against a stud bolt in the bottom of the mortar directly below its center of gravity. The scale moves tangentially to the swing of the mortar; the radius of the swing, measured from the knife-edge bearings to the center of the rod or base of the stud, is 114$\frac{7}{16}$ inches. The swing is measured to one hundredths of an inch. The standard unit of comparison is a charge of 227 grams (one-half pound) of 40 per cent "straight" nitroglycerin dynamite.

The explosive to be tested is charged in the cannon without air space around the charge. One pound of dry fire clay is used as stemming to confine the charge. The charge is fired with a No. 6 electric detonator and each result reported herein is the average of two trials agreeing within 5 per cent. In testing, the method of procedure is as follows:

Two trials are made with 227 grams of the Pittsburgh station standard 40 per cent "straight" nitroglycerin dynamite, and the average of the two swings is taken as the unit swing. One preliminary trial, or more if necessary, is then made with the explosives being tested to determine the approximate unit deflective charge. Two trials are then made with this weight of explosive and if the average swing of these two trials is within two-tenths of an inch of the standard swing the unit deflective charge is computed from this preliminary charge by direct proportion, as follows: The average swing for the explosive is to the unit swing as the trial charge is to the unit deflective charge. The distance of the cannon from the muzzle of the mortar is always one-sixteenth of an inch, a slight separation being necessary for the passage of the legs of the electric detonator or electric igniter. In order that the mortar may always hang from the same center the knife edges are trammeled before each trial.

The results of tests made to determine the propulsive effect of the various classes of explosives as measured by the pressure gages[a] and the ballistic pendulum are given in the accompanying tabulation.

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[a] See Bichel, C. E., New methods of testing explosives, 1905, pp. 54–62.

Results of tests of the propulsive effect of explosives.

Class and grade of explosive.	Diameter of cartridge.	Number of electric detonator.	Specific gravity of cartridge.	Pressure gage.			Ballistic pendulum.		Heat evolved by 100 grams of explosive.	Calorimeter percentage.	Weight of charge.	Volume of permanent gases from 454 grams of explosive.
				Kilograms per square centimeter.	Pounds per square inch.	Percentage strength.	Charge equivalent to 227 grams of 40 per cent standard nitroglycerin dynamite.	Percentage strength.				
	In.						*Grams.*		*Calor.*		*Gr.*	*Liters.*
30 per cent "straight" nitroglycerin dynamite.	1¼	6	1.31	8.874	126,230	[a]104.3	254	89.4	1,025.8	93.1	214.0	182
40 per cent "straight" nitroglycerin dynamite.	1¼	6	1.24	8,509	121,030	[a]100.0	227	100.0	1,101.8	100.0	213.0	189
50 per cent "straight" nitroglycerin dynamite.	1¼	6	1.38	9,301	132,300	109.3	215	105.6	1,222.6	111.0	213.0	225
60 per cent "straight" nitroglycerin dynamite.	1¼	6	1.37	10,311	146,670	121.2	209	108.0	1,145.8	[b]104.0	213.5	274
60 per cent strength low-freezing dynamite	1¼	6	1.14	6,797	95,830	79.2	220	103.2	663.4	[c]60.2	213.4	361
40 per cent strength ammonia dynamite..	1¼	6	1.57	8,921	126,890	104.8	243	93.4	1,122.0	[d]101.8	212.0	140
40 per cent strength gelatin dynamite.....	1¼	6	1.65	8,444	120,110	99.2	246	92.3	1,164.6	105.7	207.0	132
5 per cent granulated nitroglycerin powder.	1½	[e]6	1.21	3,350	47,650	39.4	338	67.2	744.4	67.6	205.0	136
Black blasting powder.	1½	([f])	1.25	4,817	68,520	56.6	374	60.7	789.4	71.6	205.0	150

[a] Seeming discrepancy due to difference in specific gravity.

[b] The low calorific value is due to the rather large volume of hydrogen and carbon monoxide formed, and to the fact that the calorimeter leaked slightly because of high pressures.

[c] The low calorific value is due to the large volume of hydrogen and carbon monoxide formed.

[d] No correction made for heat of condensation of water.

[e] A primer of 40 per cent "straight" nitroglycerin dynamite, representing 10 per cent by weight of the charge, was used in all tests, but the energy produced by the primer is not included.

[f] Black-powder igniter used.

COMPARISON OF EXPLOSIVES AS TO ENERGY.

As a result of tests the tabulation following has been prepared to show a comparison of various classes and grades of explosives as to potential energy and disruptive and propulsive effects.

The percentage strength representing potential energy is the result obtained with tests with the calorimeter; the percentage strength representing disruptive effect is the average of the rate of detonation, Trauzl lead block, and small lead block percentages; and the percentage strength representing propulsive effect is the average of the pressure-gage and the ballistic-pendulum percentages. In each case the 40 per cent "straight" nitroglycerin dynamite is taken as the unit of comparison with a value of 100 per cent.

Results of tests to determine potential energy and disruptive and propulsive effects of explosives.

Class and grade.	Percentage strength representing potential energy.	Average percentage strength representing disruptive effect.	Average percentage strength representing propulsive effect.
30 per cent "straight" nitroglycerin dynamite	93.1	84.1	96.8
40 per cent "straight" nitroglycerin dynamite	100.0	100.0	100.0
50 per cent "straight" nitroglycerin dynamite	111.0	109.2	107.4
60 per cent "straight" nitroglycerin dynamite	104.0	119.8	114.9
60 per cent strength low-freezing dynamite	60.2	93.5	91.2
40 per cent strength ammonia dynamite	101.8	67.9	99.1
40 per cent strength gelatin dynamite	105.7	78.4	95.8
5 per cent granulated nitroglycerin powder	67.6	21.6	53.3
Black blasting powder	71.6	6.8	58.6

The relative disruptive and propulsive effects tabulated above are shown graphically in figure 7.

PRACTICAL VALUE OF PHYSICAL TESTS.

The figures given in the foregoing table are fairly consistent with general practice, and it is believed that the classification will serve as a useful guide for comparing the practical value of explosives. It is worthy of note that the potential energy of 40 per cent strength ammonia dynamite and of 40 per cent strength gelatin dynamite (that is, the theoretical maximum work that these explosives can accomplish) is higher than that of 40 per cent "straight" nitroglycerin dynamite, but that the disruptive and propulsive effects, which represent the useful work done as shown by actual tests, are less than those of 40 per cent dynamite. Accordingly, 40 per cent "straight" nitroglycerin dynamite is more economical for general use in blasting operations if the conditions and character of the work are such as to permit its use; nevertheless, the 40 per cent strength

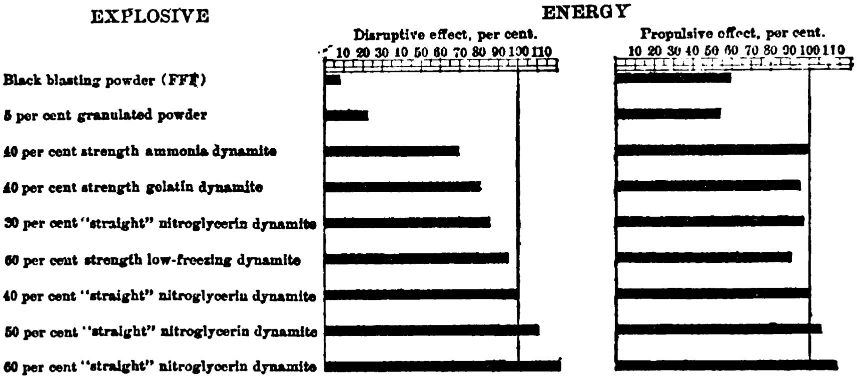

FIGURE 7.—Comparative energies of commercial explosives. Disruptive effect indicated represents averages of energies developed in the Trauzl lead-block, small lead block, and rate-of-detonation tests; propulsive effect indicated represents averages of ballistic-pendulum and pressure-gage tests.

ammonia dynamite and the 40 per cent strength gelatin dynamite are more efficient and economical for certain kinds of work that require explosives having a large propulsive effect and a comparatively small disruptive effect. For example, in blasting soft rock, 40 per cent "straight" nitroglycerin dynamite, which has a very high percussive force, may be too quick in action, whereas the ammonia dynamite or the gelatin dynamite having practically the same heaving and pushing action and less percussive force will be more suitable. The tests also show that 60 per cent strength low-freezing dynamite is not quite equivalent to the 40 per cent "straight" nitroglycerin dynamite. The 60 per cent strength low-freezing dynamite contained, by analysis, 2.61 per cent moisture and 41.43 per cent nitroglycerin. This content may be cited as one of the many reasons for the need of uniform rating of explosives in this country. It is worthy of note that black blasting powder has little disruptive effect; it has only about one-third of the disruptive effect of granulated nitroglycerin powder.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 12. The behavior of nitroglycerin when heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp., 1 pl.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions; report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 8 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1912. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1913. 14 pp.

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Bulletin 49

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, Director

SMOKE ABATEMENT
AND
CITY SMOKE ORDINANCES

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

Second edition, revised, October, 1912.
First edition issued in September, 1912.

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PREFACE.

The Bureau of Mines is endeavoring to ascertain how mineral fuels in which the Government has a direct interest, by ownership or use, can be utilized with highest efficiency. For this reason the bureau has been, and is, carrying on investigations to ascertain the conditions of furnace construction and management that are necessary to insure the smokeless combustion of the different coals that are found in public lands or are purchased for Government ships and power plants.

Another reason for the bureau undertaking these investigations is the need of better furnace management and a more careful selection of fuel at many Government plants. There are Federal buildings in hundreds of cities. The coals available at many of these cities differ greatly in quality, and the furnaces in some of the Federal buildings were not designed for efficient utilization of the cheapest available coal. Hence, some of the boiler plants smoke badly unless fed with low-volatile coal and have caused repeated complaints not only from neighboring property owners who have suffered damage, but from persons endeavoring to create a civic pride in clear air.

In the course of its fuel investigations the bureau has noted the conditions governing fuel consumption in different cities and has studied the attempts made by these cities to abate smoke through the passage of ordinances imposing penalties on smoky stacks. Some results of that study are presented in this report. The most important conclusion reached is that smoke abatement by ordinance can not hope to succeed unless supported by public sentiment and that a smoke ordinance should look to future prevention rather than to immediate prohibition. In other words, strict control of furnace construction offers much greater hope for smoke abatement than desultory imposition of severe penalties on the escape of " dense " or " black " smoke.

SMOKE ABATEMENT AND CITY SMOKE ORDINANCES.

By Samuel B. Flagg.

INTRODUCTION.

GENERAL INTEREST IN SMOKE ABATEMENT.

Almost from the inception of the fuel-testing work begun by the Government in 1904 the determination of ways and means for smokelessly burning fuels from different sections of the United States has been deemed of great importance by the officials in charge of the work. The results of some of the investigations along this line have been published as bulletins[a] of the United States Geological Survey and of the Bureau of Mines. The large demand for these bulletins has indicated that the subject is of much interest to the public.

Since the fuel-testing investigations were begun in 1904, and in some measure because of them, a marked improvement has been made in the smokeless burning of many fuels, and particularly in the burning of bituminous coal. This advance has resulted partly from a desire to improve general power-plant economy, but more largely from a public demand for less smoke. Unfortunately, many of those who have been working on the problem of smoke prevention, or smoke abatement, have not had a thorough understanding of the basic principles involved, and consequently much effort has been misdirected. Even to-day smoke prevention means to a large number of persons the application of some special device, some "smoke consumer," which, if placed in the stack or in the smoke passages, will in some way consume the smoke.

CAUSE OF SMOKE.

Although such a method of preventing smoke may not be an impossibility, it is impractical. Smoke is usually caused by relatively cool surfaces being too near to the fuel bed or to the point where fuel is fed into the furnace, and the logical way of preventing smoke is to move these cool surfaces, such as the water-cooled surfaces of a boiler, farther from the fuel bed, change the method of feeding the fuel into the furnace, or make additional provision in the furnace for mixing the combustible gases with the incoming air. To illustrate: If a small block of cold iron be lowered well into the chimney of an ordinary kerosene lamp burning with normal height of flame, smoke immediately appears at the top of the chimney because the cool surfaces of the iron lower the temperature of the gases within the chimney below the temperatures at which those gases burn. To prevent this smoke it is unnecessary to attach a "smoke consumer" to the top of the chimney; if the block of iron be gradually raised the smoke decreases, and when raised to a certain height the iron no longer causes the lamp to smoke.

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[a] Randall, D. T., The smoke problem at boiler plants, a preliminary report: U. S. Geol. Survey Bull. 334, 1908, 26 pp. (revised and reprinted as Bull. 39, Bureau of Mines); Randall, D. T., and Weeks, H. W., The smokeless combustion of coal in boiler furnaces, with a chapter on central heating plants: U. S. Geol. Survey Bull. 373, 1909, 188 pp. (revised and reprinted as Bull. 40, Bureau of Mines).

RESULTS OF SMOKY CONDITIONS.

In popular discussions of the smoke problem attention is frequently called to the "enormous losses" resulting from the failure to burn the solid carbon particles that pass out of the stack in smoke. If this were the only, or even the greatest loss attributable to smoke emission, the need for smoke abatement would concern only those using a given fuel and might be overlooked, inasmuch as the heating value of the carbon escaping as solid particles represents only 1 to 3 per cent of the total heat units in the coal used. There are, however, other losses through incomplete combustion that usually accompany the loss noted and are of greater moment; they result from the partial burning of carbon to carbon monoxide (CO), and from the escape of unburned hydrogen and hydrocarbons. Under some conditions of furnace design the latter losses may amount to 20 per cent of the heating value of the coal.

When furnaces are operating under smoke-producing conditions, not only is fuel wasted but the damage resulting from the effects of the smoke is enormous and affects the public directly. It has been estimated that in Cleveland, Ohio, this damage amounts to $12 per capita per annum. In Chicago, Ill., the damage has been estimated to equal four-fifths of all the taxes levied in that city for municipal purposes, or a sum equivalent to at least 80 per cent of the cost of all the coal burned in the city. The many ways in which this damage makes itself felt will not be discussed in this bulletin, but some of the principal ones are: By increased expenditures for repairing and repainting exteriors and interiors of buildings, for artificial light made necessary by the decreased amount of sunlight, for laundering and cleaning, and by injury to vegetation.

DEMAND FOR SMOKE ABATEMENT.

With the introduction of special methods or improved equipment for burning different fuels came the proof that smoke could be largely reduced or entirely prevented. At the same time people began to realize the losses and the damage resulting from smoke emission and to demand that steps be taken to abate smoke. This demand has been expressed by the action of chambers of commerce and of civic associations and leagues, as well as by the passage and enforcement of smoke ordinances by nearly all the large cities of the country. It is quite certain that the greatest advances in smoke abatement in our cities have come in the past, and must come in the future, through the organized effort of the city smoke-inspection departments, supplemented by the active cooperation of citizens.

In connection with the fuel investigations conducted by the Bureau of Mines much information has been accumulated as to the smoke-abatement activities in various cities. The essential features of the information are presented in this report, which, it is believed, will be of public interest and benefit, especially to those communities that are just beginning organized effort to abate unnecessary smoke.

ACKNOWLEDGMENTS.

The writer takes this opportunity of acknowledging the interest and cooperation of the smoke departments of many cities. He is indebted to H. M. Wilson, engineer in charge of the bureau's testing station at Pittsburgh, Pa., and to others for suggesting questions to be included in the circulars of inquiry, and to O. P. Hood, chief mechanical engineer of the bureau, for helpful criticism of this discussion. In the preparation of the forms of smoke ordinances herein suggested, frequent reference has been made to the report of the Chicago Department of Smoke Inspection, issued in 1911, and also to the Chicago and the Des Moines ordinances. From these sources much material has been taken without substantial change.

FACTORS AFFECTING SMOKE CONDITIONS IN CITIES.

There are probably no two cities in the United States in which the conditions affecting the problem of smoke abatement are even approximately the same. The differences are caused by a number of factors, among which may be mentioned the status of public opinion, the existence or lack of proper smoke ordinances, organization and personnel of smoke departments, topographic and climatic conditions, character of the fuel used for commercial and domestic purposes, nature and extent of the industrial activities, and the volume of railroad and steamboat or steamship traffic.

A strong public sentiment in favor of smoke abatement is almost an absolute necessity if satisfactory results are to be accomplished. If the smoke ordinance is defective or if the organization charged with its enforcement does not see that its provisions are carried out there will be slow progress. Topographic and climatic conditions have their influence upon the location of industrial plants, upon the location of railways and their grades, and upon the quantity of fuel used for different purposes. As to the character of the fuel, it can readily be seen that where anthracite coal, fuel oil, or natural gas is available and can be economically used in any considerable percentage of the furnaces, smokeless combustion in those furnaces can be obtained with relative ease. It is well known, however, that brick kilns, heating and annealing furnaces, puddling furnaces, as well as locomotive and steamboat boilers, are among the most difficult to fire without smoke, so that the proportion of such furnaces to the total number in a city must be taken into account in making comparisons. According to the Chicago smoke department,[a] locomotives produce 43 per cent of all the smoke emitted in Chicago, and the special furnaces are responsible for 12½ per cent.

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[a] Report of the Department of Smoke Inspection, city of Chicago, 1911, pp. 39–40.

The status of the smoke-abatement work in each of the principal cities is due mainly to the influence of the several factors mentioned. The extent to which any one of these factors is responsible for the existing conditions in a particular city could be estimated only by those thoroughly familiar with every phase of the work in that city, and acquainted in some degree with conditions in other cities as well.

Undoubtedly the greatest improvement in connection with smoke emission has been made in the stationary steam-boiler furnaces, although in some localities the amount of locomotive and steamboat smoke has been greatly reduced. The explanation for this greater improvement in the one class of furnaces lies in the fact that much more is known regarding the proper design of such furnaces, the conditions of their operation and the limitations of their design are ordinarily not so exacting, and the personal element is more easily controlled. Most of the railroads issue to their enginemen instructions for firing so as to prevent smoke and waste of fuel, and some of the roads maintain their own force of instructors and smoke inspectors. Where such inspectors are detailed and the firemen follow closely the instructions given, a marked reduction in smoke is noted. Ordinarily more attention is given to passenger locomotives, and to-day the engines for freight service and shunting work produce more smoke than those in passenger service. Another, and one of the most serious phases of the problem of reducing the smoke incident to the operation of railroads, is the elimination of smoke from roundhouses and from engines standing in yards.

Some of the special furnaces have been made more nearly or quite smokeless by the use of gas, fuel oil, or pulverized fuel, but the adoption of these fuels does not guarantee the elimination of smoke; in fact, the writer has seen some furnaces using them that were among the worst offenders. In some cities the difficulty of making the stacks of these special furnaces smokeless has been given consideration, and such stacks have been exempted by the ordinances; in other cities the smoke departments, realizing this difficulty and following a general policy of cooperation with plant owners, have worked with the owners or operators to bring about as much improvement as possible and have brought no suits so long as the operators appeared to be making every effort to comply with the ordinances.

STATUS OF SMOKE-ABATEMENT WORK IN THE UNITED STATES.

With the idea of learning more definitely the status of smoke-abatement work in this country the Bureau of Mines recently sent out circulars of inquiry to the officials and the antismoke organizations of all the principal cities. From the replies to these circulars and from information obtained by personal inspection condensed statements in regard to the existing conditions in some of these cities have been prepared and are given in the following pages.

In studying the data submitted by the smoke inspectors or other officials the cities were divided according to population into three main groups, viz, (1) cities having less than 50,000 inhabitants, (2) cities of 50,000 to 200,000 inhabitants, and (3) cities of over 200,000 inhabitants.

CITIES OF LESS THAN 200,000 INHABITANTS (GROUPS 1 AND 2).

Out of approximately 240 cities in the first group only 12 reported having either a smoke ordinance or an official charged with smoke inspection. From the second group about 60 replies were received, and of the cities represented by them 17 are making more or less vigorous efforts to suppress the nuisance. Of the 17 cities mentioned, the most active are Des Moines, Iowa; Lowell, Mass.; Syracuse, N. Y.; Toledo, Ohio; Richmond, Va.; and Atlanta, Ga. Des Moines has a new and well-drafted ordinance resembling in many respects the Chicago statute, and its citizens seem to have a decided spirit of cooperation. In Richmond, Va., an ordinance was passed prohibiting the use in certain sections of the city without a permit from the city council of any fuel except anthracite coal. This ordinance was afterwards declared unconstitutional. The city of Nashville, Tenn., is at this time considering the passage of an ordinance the proposed form for which is modeled rather closely after the commendable Chicago and Des Moines ordinances. The reply from one of the cities in the group says that smoke has been found "a nuisance that can not be abated in the city of ————, for the reason of its being a manufacturing city." The fallacy of such a statement is now recognized by a number of the more important manufacturing cities, and in them, in an increasing measure, the smoke nuisance is being intelligently and successfully combated.

CITIES OF OVER 200,000 INHABITANTS (GROUP 3).

Of the 28 cities having over 200,000 population, 5 are making practically no effort toward smoke abatement, but in 3 of these fuel oil is used almost exclusively, and the smoke problem is not serious. A statement concerning each of the 28 cities in group 3 follows:

Baltimore, Md.—The Baltimore ordinance prohibits the emission of dense smoke within the city limits for more than six minutes in any one hour. Furnaces used solely in connection with manufacturing or in buildings used exclusively for such purpose are exempt. With the possible exception of the railroad smoke this city has a smoke problem comparatively easy of solution, but progress in that direction has been very slow because of the general public's lack of interest in smoke abatement. This lack of support has probably resulted largely from the mistaken belief held by many people that systematic or organized effort toward the suppression of the smoke nuisance would bring about injury to the commercial interests of the city.

Boston, Mass.—In Massachusetts, as in several other States, there is a State law prohibiting the emission of dense smoke within the corporate limits of cities having more than a given population. The city of Boston and some of the adjacent territory are governed by a special enactment of the State legislature. The Massachusetts Board of Gas and Electric Light Commissioners has general supervision of the enforcement of the enactment, and the board is empowered to appoint a smoke inspector and such deputy inspectors, clerks, and stenographers as are provided for. The expense incurred in connection with the work is prorated among the several municipalities according to their State tax.

The Boston ordinance differs from other statutes in force in that it classifies stacks according to their size and the character of furnaces they serve and specifies increasing restrictions each year until 1913. There is considerable support for the enforcement of the statute and good results are being reported.

Buffalo, N. Y.—Section 1 of the Buffalo smoke ordinance provides as follows:

> It shall not be lawful within the limits of the city of Buffalo for any persons or person, firm or corporation, or any servant, agent, or employee of any person, firm or corporation to permit or allow, or cause to be permitted or allowed, the discharge or escape into the open air of large quantities of smoke, soot, dust, gas, steam or offensive odor, or to permit or allow any smoke, soot * * * to escape in such manner or in such quantities as to cause or have a natural tendency to cause injury, detriment, or annoyance to any persons or person or the public, or to endanger the comforts, repose, health, or safety of any persons or person or the public, or in such manner as to cause or have a natural tendency to cause injury or damage to business or property.

The restrictions of this section are so sweeping in their nature that it is doubted if they would be sustained in the courts. The emission of any smoke at all could be construed a violation of the section, although the intent of the framers of the ordinance probably was to prevent only the emission of dense smoke.

For the enforcement of this ordinance it is provided in section 4 that—

> It shall be the duty of the board of public works to investigate all complaints made to it of a violation of any of the provisions of this ordinance and report the same to the corporation counsel; it shall be the duty of each inspector connected with the bureau of streets of said city, and of all police officers of said city, to immediately report to said board all persons, firms, or corporations guilty of a violation of this ordinance, together with the names and addresses

of all witnesses having knowledge concerning or being in the possession of facts showing such violation; each and every such inspector or police officer shall have the right and authority at all reasonable hours to visit and inspect premises and all machinery, boilers, furnaces * * *.

It might seem from the foregoing that abundant provision had been made for the enforcement of the ordinance. Reports indicate, however, that the ordinance is not observed and that violators are not prosecuted. This condition is rather to be expected than otherwise because of the divided responsibility for the enforcement of the ordinance. In order to carry on successfully the work of smoke abatement in a city of large size certain individuals must be held responsible for the enforcement of the smoke ordinance and for that alone.

Chicago, Ill.—The ordinance passed by the city council of the city of Chicago, in its essential features, provides for certain officials and specifies their duties as follows:

(*a*) A department of smoke inspection, the head of which is known as the smoke inspector.

(*b*) A smoke inspector appointed by the mayor by and with the advice of the city council.

(*c*) That the person so appointed shall be a " mechanical engineer, qualified by technical training and experience in the theory and practice of the construction and operation of steam boilers and furnaces, and also in the theory and practice of smoke abatement and prevention."

(*d*) A chief assistant smoke inspector to be appointed by the smoke inspector as provided by law.

(*e*) The qualifications of the chief assistant smoke inspector to be the same as for the smoke inspector.

(*f*) As many deputy smoke inspectors, assistant smoke inspectors, clerks, and stenographers as shall be provided for by the city council.

(*g*) Appointment by the mayor of a smoke-abatement commission of eight members to act as advisors to the mayor in the organization of the smoke department and to the smoke inspector in the conduct of the department.

(*h*) An advisory board of three consulting engineers of recognized standing, who have had the necessary experience to fit them to act as advisors on engineering questions to the commission, the smoke inspector, and the members of the department.

The Chicago ordinance also provides:

(*i*) That no new power plants are to be built or old plants reconstructed until plans and specifications for such work have received the approval of the smoke inspector, and until a permit for such work has been issued.

(*j*) That no new or reconstructed plants shall be used until inspected by the smoke department and found to be properly constructed, and until a certificate has been issued.

(*k*) That permits shall be procured before making any alterations in chimneys or furnaces, provided such alterations affect in any way the prevention of smoke. Minor changes or emergency repairs not involving a change in the method of preventing smoke may be made without a permit. For violation of this provision a fine of $25 for each day upon which the alteration is prosecuted is the penalty.

(*l*) That the emission of dense smoke from any stack, except for a period of six minutes in any one hour during which the fire box is being cleaned or a new fire is being built therein, is a nuisance and may be summarily abated. Penalty for violation of this provision is a fine not less than $10 nor more than $100 for each offense.

(*m*) That the fees for inspecting plans and for examining plants shall be as follows, the fee to include the issuing of a permit or certificate:

For inspecting plans and specifications of new plants and of plants about to be reconstructed	$2.00
For inspecting plans for repairs and alterations	1.00
For examining plants after erection or reconstruction and before its operation and maintenance	3.00

(*n*) That the possession of a permit or certificate issued by the smoke inspector shall not exempt anyone from penalties for violations of the ordinance.

(*o*) That for violation of any of the provisions of the ordinance (except as otherwise stated) the penalty shall be a fine of not less than $25 nor more than $100 for each offense.

(*p*) That the smoke inspector shall keep a complete record of all plans submitted, of all permits issued, of all plants examined, and of all certificates issued.

(*q*) That if any person acting on behalf of the city under the provisions of this chapter shall take or receive any money or any valuable thing for the purpose of deceiving or defrauding any person or persons, or for the purpose of favoring any person or persons, or if any inspector shall recommend the issue of any certificate of inspection without having at the time stated thoroughly examined and tested the furnace, device, or apparatus so certified, he shall be fined $100 for each offense.

Although there is to-day in Chicago an immense amount of coal smoke from all sorts of furnaces, there is certainly no other American city that has made such marked progress toward the scientific solution of the smoke problem. This result is due very largely to the fact that smoke abatement has there, more generally than elsewhere, been recognized and attacked as an engineering problem, and greater efforts have been made to obtain cooperation between plant owners and operators and the city officials. As the result of these efforts, for practically every type of boiler for stoker and for hand-fired operation, there have been developed settings that make possible the attainment of average or even high boiler capacities, while keeping the density of the smoke produced well within that allowed by the ordinance.

The furnace designs developed for hand-fired boilers stand out as possibly the most distinctive feature of the work in Chicago, because of the comparatively little effort that has been put upon the scientific solution of this part of the smoke problem in other cities. The settings include arches, piers, or walls for the purpose of maintaining a sufficiently high temperature and of obtaining the necessary mixing of the air and gases. Provision is usually made for the admission of extra air immediately after firing, and in many installations steam jets are also required instead of entire reliance being placed upon the other mixing devices mentioned. However, one of the principal contributing factors to the lessening of the smoke from these hand-fired plants has been the knowledge of the firemen that their stacks might at any time be watched by an assistant inspector. The greater care in firing that has resulted from this knowledge has, of course, decreased the smoke. The same result will follow in any city when the necessity for such care is once realized.

Cincinnati, Ohio.—At present (May, 1912) Cincinnati is considering the adoption of a revised smoke ordinance. The ordinance in force provides for a method of grading the density of smoke as well as for ways and means of regulating its emission. The escape of dense smoke from any sort of stack, "except for a period of or periods aggregating six minutes in any one hour during which the fire box is being cleaned out or a new fire is being built therein," is declared a nuisance. Any emission in excess of the above is prohibited, and violators are, upon conviction, subject to penalties of increasing severity with the repetition of the offense.

The proposed statute increases the allowable period of dense smoke emission from 6 to 10 minutes in any one hour, and provides that "the careless or negligent emission of dense smoke as above described from a locomotive engine is hereby declared to be a nuisance." The clause just quoted is believed to make the new ordinance weaker than the old and to make more difficult the abatement of locomotive smoke.

The proposed ordinance is also defective in that the assistant chief smoke inspector and the deputy smoke inspectors are required to have certain qualifications essential to the intelligent prosecution of smoke-abatement work, whereas the head of the department is not expressly required to possess them.

The approval of plans for all new boilers and furnace-construction work and of all repair work is now required before the work can proceed. A certificate of inspection must also be obtained from the smoke inspector after completion of the construction work and before the furnace is operated.

Cleveland, Ohio.—The smoke ordinance in Cleveland allows no period of emission of dense smoke, stating simply that the emission of dense black or gray smoke is a nuisance and is prohibited. Inspection of plans for new work is provided for in the ordinance, and the prosecution of such work without a permit from the smoke inspector is prohibited. The city officials have accomplished much in the way of improving conditions, and their efforts have been actively supported and supplemented by the Cleveland Chamber of Commerce, but the rapid growth of industrial plants in and near the city has had a tendency to make the improvement seem less than it really has been. There is still, however, an immense amount of coal smoke that can and will be eliminated if there is no relaxation of efforts toward the accomplishment of this end.

Denver, Colo.—According to Denver's smoke ordinance, the emission "of dense smoke within the corporate limits of the city and county of Denver is * * * declared to be a public nuisance." Violators of this section are punishable by fine, but the ordinance also provides that "in any suit or proceeding under this article it shall be a good defense if the person charged with the violation thereof shall show to the satisfaction of the court trying the case that there is no known practical device, appliance, means, or method by the application of which * * * the emission or discharge of the dense smoke complained of in that proceeding would have been prevented."

The smoke inspector may "require all steam furnaces or other furnaces * * * to be so constructed, or if already constructed to be so altered, as to lessen or diminish and prevent the * * * emission of such dense smoke therefrom, provided that in any suit * * * it shall be a good defense if the person * * * shall show to the satisfaction of the court * * * that such construction or alteration would not appreciably lessen or diminish or prevent the production and emission of dense smoke."

It is also required that any person having charge of the stoking of any boiler or other furnace shall so stoke it that dense smoke shall not be emitted therefrom. This section provides also that it shall be a good defense if the person charged with the violation shall show to the satisfaction of the court that the smoke was emitted without fault on his part.

Detroit, Mich.—The smoke ordinance in force in Detroit at the present time was approved July 29, 1907. Within the past year or two there has been some agitation to have the statute modified in certain respects, but no definite action has yet been taken. The present ordinance prohibits the emission at any time of dense black or gray smoke "from any smokestack or chimney used in connection with any steam boiler, locomotive, or furnace of any description, in any apartment house, building, boat, or any other structure, or in any building used as a factory, or for any purpose of trade, or for any other purpose whatever within the corporate limits of the city of Detroit * * *" Another clause requires that all furnaces shall be so constructed, altered, or equipped as to prevent the emission of such dense black or gray smoke, and all plans for such construction or alteration are subject to the approval of the smoke inspector.

The board of health, to whom the smoke inspector reports, has published and distributed to the engineers and firemen of the city a small pamphlet on smoke abatement, in which are given instructions for firing several different types of furnaces.

The general policy followed in Detroit in the smoke-abatement efforts is one of education, and operators are urged to install mechanical stoking equipment wherever practicable.

Indianapolis, Ind.—The emission of dense smoke from any stack or chimney, except that of a building used as a private residence, is declared to be a nuisance, and is prohibited. The smoke inspector, who is a deputy of the inspector of buildings, is given authority to require all furnaces to be so constructed, or if already constructed to be so altered, as to prevent the emission of dense smoke therefrom. Permits must be obtained from the smoke inspector before new construction, reconstruction, or alteration of boiler or other furnaces can be started.

The Indianapolis ordinance further specifies that when the smoke emission "is owing to the construction of the furnace * * * or other engineering details relating to boiler or furnace construction or connection he (the smoke inspector) shall make statement of the cause of such nuisance and report to the owners or operators as to necessary changes, alterations, or additions, and fixing a limit of time for such changes * * * to be made * * *," this time not to exceed three months. "In the event, however, that it becomes necessary to install stokers, six months shall be given." In cases where the trouble is primarily overloading, or where alterations will not solve the problem and it is necessary to install new equipment, four months is allowed in which to complete the work if tubular boilers are to be installed, and if water-tube boilers are to be put in the time allowance may be increased to nine months.

Jersey City, N. J.—At present (1912) Jersey City has two smoke ordinances, one prohibiting the emission of dense smoke from locomotives and the other relating to the smoke from stationary boilers and furnaces. Two smoke inspectors, appointed by the board of finance and assigned to the law department, are charged with the duty of smoke inspection. There is no State law relative to smoke emission, but efforts are being made to have such a law passed.

The ordinance relating to the emission of smoke from stationary boilers and furnaces states that "it shall be unlawful to permit the emission of dense smoke from any chimney or smokestack connected with any stationary engine, steam boiler, furnace, range, or fireplace within the limits of Jersey City which smoke contains soot or other substance in sufficient quantity to permit the deposit of such soot or other substance on any surface within said limits."

The other smoke ordinance prohibits "the emission of dense smoke from any stack connected with any engine or locomotive within the limits of Jersey City which smoke contains soot or other substance in sufficient quantity to cause injury to health or damage to property within the corporate limits of said city." Another section of this ordinance states that "any owner, lessee, occupant, manager, engineer, or fireman of any engine or locomotive * * * who permits or allows * * * to be emitted from such smokestack dense smoke containing soot or other substance in such quantity as to cause injury to health or damage to property," shall, upon conviction, pay a penalty of $50 for each violation.

Reports from Jersey City state that the city is "not having very much trouble with the operators of stationary plants, the worst offenders * * * being railroads." The validity of the ordinance relating to stationary plants has not been questioned, but the validity of the other statute is now being tested in the courts. In a number of cases the railroads were convicted in the lower courts, but appeals were taken and these cases are now before the State supreme court. One of the points to be decided by the court is whether or not, under the present laws, the governing bodies of cities in New Jersey have power "to the extent of the abatement of the so-called smoke nuisance."

Both of the present smoke ordinances are open to the objection that they require absolutely smokeless operation, if the courts consider as "dense" all smoke that "contains soot or other substance in sufficient quantity to permit the deposit of such soot or other substance on any surface within" the city limits, or "in sufficient quantity to cause * * * damage to property within the corporate limits."

Kansas City, Mo.—The present smoke ordinance in Kansas City, Mo., declares the emission of dense smoke within its corporate limits to be a nuisance and prohibits such emission. The ordinance is considered to have been violated whenever such smoke is emitted from any stack or chimney, except that of a building used exclusively for residence purposes, "provided it shall first be shown to the satisfaction of the court trying the case that there is or are no known practicable device or devices, appliance or appliances, means or method by the application of which to the building, establishment, or premises the emission or discharge of dense smoke from which complaint is made, whereby at reasonable expense prevention can be had." The weak point in the foregoing provision is that the inclusion of the word "reasonable" in the last clause is apt to lead to much controversy.

Another section provides that "No person, firm, or corporation engaged in the business of manufacturing or selling smoke-consuming devices shall attach any said device to any boiler without first obtaining from the health officer a permit therefor, for which the sum of two dollars ($2) shall be paid to the treasurer of Kansas City, and it shall be the duty of said health officer upon the payment of said permit fee to forthwith issue said permit * * *." It is believed that the wording of this section makes it obligatory on the part of the health officer to issue a permit for the installation of any device upon the payment of the permit fee, whether the device is known to be a proven success or a total failure as a means for preventing smoke.

Authority is also given to this same officer to inspect all "steam furnaces carrying thirty (30) pounds of steam or more, except in buildings used for private residence purposes exclusively * * *;" and, if smoke is being emitted, to require these furnaces to be so altered as to prevent the emission of all unnecessary smoke therefrom. It is provided, however, that "in any suit or proceeding for the violation of this section it shall be a good defense if the person charged with the violation thereof shows to the satisfaction of the court * * * that such alterations would not appreciably lessen or diminish or prevent the production and emission of dense smoke." At present there is no inspector, so that little active work can be done.

Los Angeles, Cal.—The almost exclusive use of oil fuel makes the solution of the smoke problem in Los Angeles much easier than in a city in which bituminous coal is generally used. The Los Angeles ordinance establishes a standard of density for smoke which is 19 per cent black, or a density about that of No. 1 of the Ringelmann chart.[a] The emission of smoke of greater density than this standard for more than five minutes in any one hour is prohibited. It should be noted at this point that, although the firing of oil fuel so as to prevent dense smoke is less difficult than similar firing of coal, the Los Angeles specifications as to standard of density and time of emission permissible are much more difficult to comply with than similar specifications in other cities having smoke ordinances. It appears that buildings used for private-residence purposes exclusively are not exempted in Los Angeles as they are in some other places.

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[a] See p. 27.

No provision is made for the inspection of drawings of new installations or for alterations of furnaces. It is specified that no person shall erect or maintain any chimney or smokestack within 50 feet of any window of any adjacent building unless the top of such chimney "shall be higher than every portion of such window * * *."

Louisville, Ky.—In the city of Louisville the emission of "soot, black or dense gray smoke" from any chimney or smokestack is prohibited. The ordinance does not, however, apply to buildings used exclusively for private residence purposes, nor to locomotives attached to regularly scheduled passenger trains entering, leaving, or standing at depots in Louisville, or attached to through freight trains entering or departing from the city.

The inspector of buildings, to whom the smoke inspector reports, is given authority to require that all boilers and furnaces shall be so designed or shall have such "an efficient smoke preventative" attached to them that the provisions of the above paragraph may be complied with. If, in the judgment of the inspector of buildings, it shall be impracticable so to design or to equip locomotives or small stationary or portable boilers, he may require the use of such fuel and such methods of operation as will make possible compliance with the above specifications.

Plans for new construction or for alteration of furnaces are subject to the approval of the inspector of buildings. It is further specified as a duty of this official that "when from personal knowledge or from any other source the inspector or any of his assistants obtains information that any provision of this ordinance has been or is being violated, the inspector of buildings himself or by one of his assistants shall lodge complaint with the city court against any and all who are guilty of said violation." The purpose of the above specification would, it is believed, be better served if the inspector were required to investigate any report of violation that might be communicated to him and to lodge complaint with the city court whenever such violations could be proved.

The ordinance further provides as follows: "The provision of this ordinance shall not apply to any building, establishment, or premises where there is no known practicable device, appliance, means, or method by the application of which to said building, establishment, or premises the emission * * * of dense smoke * * * could have been or can be prevented." This immunity lasts only so long "as there is no known practicable device, appliance, means, or method * * *." In case of a disagreement as to the practicability of any device "an appeal shall lie from the decision of the inspector of buildings to the board of public safety."

Milwaukee, Wis.—A new smoke ordinance passed by the common council of Milwaukee in October, 1911, includes among its provisions that the smoke inspector "shall be appointed by the mayor, subject to confirmation by the common council, and shall hold office for a term of four years * * *." It also specifies that "no person shall be eligible to said office unless he is by trade or profession a steam or mechanical engineer of at least five years in working at said trade or profession."

The section relating to smoke emission states: "To emit or cause or permit to be emitted into the open air within the corporate limits of the city of Milwaukee or within 1 mile therefrom any dense smoke shall be and is hereby prohibited, provided that nothing herein contained shall prohibit the emission of dense smoke not to exceed five minutes in any one hour of the day or night."

A permit must be procured from the smoke inspector before work can be started on the construction or alteration of "any stationary steam plant, boiler, or furnace. * * * All accidents to stationary steam boilers, furnaces, or smoke-preventing devices shall be reported to the smoke inspector in writing, giving the nature of the accident and the time required to repair the same."

The prohibition of dense-smoke emission outside of but within 1 mile of the city limits is made possible because of a State enactment concerning the production of smoke. The latest report of the smoke inspector states that railroad officials are cooperating with the city department and are designating additional inspectors of their own to further reduce the railroad smoke.

Minneapolis, Minn.—The emission of dense smoke from any sort of smokestack or chimney is prohibited in Minneapolis. The city ordinance states that "the use of soft coal in traction engines, switching engines, and locomotive engines in the city of Minneapolis is hereby declared to be a nuisance; and such use of soft coal, other than smokeless coal, in the city of Minneapolis is hereby prohibited."

The railroad-smoke problem is said to have been "pretty well solved as to locomotives," but the roundhouse smoke is said to be troublesome still.

The ordinance has been tested in the courts and was sustained by the State supreme court in 1911.

Newark, N. J.—The one feature of the Newark smoke ordinance that is worthy of special notice is contained in section 1, which states "that it shall be unlawful to permit the emission of dense smoke from any smokestack or chimney connected with any stationary engine, steam boiler, locomotive, * * * which smoke contains soot or other substance in sufficient quantities to permit the deposit of such soot or other substance on any surface within the limits of said city." The incorporation of the last clause in the above sentence weakens the ordinance and makes it difficult of enforcement. Some specification as to what constitutes dense smoke is desirable, but a method of comparison with some such standard as the Ringelmann chart[a] is believed to best answer the purpose.

The smoke inspector may grant immunity to any plant owner or operator for a period of 30 days during which alterations or changes are being made for the purpose of eliminating smoke, provided the plans for such changes are approved by the inspector. The above period may be extended by him if at the expiration of the 30 days the work is not completed and if he is satisfied that the owner or operator is acting in good faith; such extension is not to exceed in all four months from the first approval of said plans. Authority is given to the finance committee of the common council under the same circumstances to still further extend the period of immunity so much "as to them may seem reasonable * * *." The approval of plans for such changes "shall not relieve such owner or owners * * * from liability for violations * * * of this ordinance if such alterations, changes, or device, when completed or installed, fail to prevent the emission of smoke of the kind prohibited by this ordinance."

New Orleans, La.—In New Orleans there is no smoke ordinance, and no smoke-abatement work is being done by the city officials.

New York, N. Y.—The New York smoke ordinance prohibits the emission of dense smoke within the city or on the waters adjacent to and under the jurisdiction of the city from any chimney or stack or any other source and prescribes penalties for violations thereof. In the designing of new work, the city does not attempt to exercise supervision with the idea of preventing the installation of furnaces which are, from the standpoint of smoke prevention, poorly arranged. The result of this laxity, together with the availability of the smaller and cheaper sizes of anthracite, has been slow progress in the development of furnaces suitable to the use of the bituminous coals available in that market. Many plants are continuing the use of anthracite coal, or a mixture of bituminous and anthracite, at a greater fuel cost per unit of evaporation, because of the belief that smoke can not be successfully and economically prevented if soft coal is used.

Philadelphia, Pa.—For determining the density of smoke the smoke ordinance of Philadelphia establishes a standard, and the emission from any stack or chimney of smoke of greater density than this standard is prohibited. The following exceptions to this limitation are quoted from the ordinance:

> *Provided, however,* That it shall not be unlawful to permit or suffer the emission or escape of such smoke of a greater degree of darkness than No. 1

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[a] See p. 27.

scale for a period of not more than five consecutive minutes from any locomotive or river steam craft standing with banked fires or engaged in shifting or for a period of not more than 10 consecutive minutes from any locomotive or steam river craft while its fires may be in process of cleaning or preparing for starting: *And provided further*, That none of the provisions of this ordinance shall apply to a locomotive or, locomotives or river steam craft in continuous transit through or across the city or while entering or departing therefrom.

The provisions of this ordinance shall not apply at any time between the hours of 4 o'clock a. m. and 7 o'clock a. m.

The effect of these exceptions is practically to exempt locomotives and steam river craft from observance of the ordinance.

Pittsburgh, Pa.—A new ordinance passed in October, 1911, by the city council provides for the regulation of smoke emission from all furnaces except mill heating and puddling furnaces and those in private residences. No steam-boiler or other furnace can be constructed within the city until an application for a certificate, accompanied by plans and specifications showing the means of smoke prevention, has been approved by the smoke inspector. It is specified that no discrimination shall be exercised for or against any method for eliminating the smoke; also that the issuance of or the holding of a permit does not exempt anyone from prosecution for violation of the ordinance.

All furnaces except those above mentioned must be so constructed and operated as not to exceed eight minutes' emission of dense gray or black smoke in any one hour, provided, however, that " during the first hour in which a new fire is being kindled in or under a cold boiler or other furnace, excepting in private residences, mill heating furnaces and puddling furnaces, sixty (60) minutes once a day for the first year, forty-five (45) minutes once a day for the second year, and thirty (30) minutes once a day for the third year and each and every year thereafter of dense black or dense gray smoke issuing from the stack or chimney thereof will not be a violation of this ordinance; but, during each succeeding hour that such boiler or other furnace is in service, more than eight (8) minutes of dense black or dense gray smoke issuing from the chimney or stack thereof in any one hour shall be and the same is a violation of this ordinance." Not only is this allowable time of smoking during the period of building fires too liberal, but such a provision makes much more difficult the work of the smoke inspector. In a plant where several boilers are connected to one stack it is possible for such a stack to smoke for as many hours as there are boilers without the ordinance being violated, provided that a new fire is started each hour. It is also necessary for the smoke inspector to go into the plant each time the eight minutes' emission is exceeded to see if a new fire is being started.

The ordinance requires that when the provisions are being violated the smoke inspector shall investigate, shall make complaint to the persons so offending, and, if the cause thereof is unskillful stoking, shall give proper instructions to correct the trouble, at the same time making "complaint to the director of the department of public health against any and all such persons violating this ordinance." If the trouble is due to improper construction of furnace or stack connections, or other engineering details, "he shall make statement of the cause of such offense and report to the owners or operators as to the necessary changes, alterations, or additions to be made." These must be completed within six months. If the installation of additional boiler units or the entire reconstruction of the existing units is necessary, "not more than nine (9) months shall be allowed in which to complete such changes." Notices must be in writing, and at the expiration of the time allowance the chief smoke inspector must investigate and make report to the director of the department of public health as to the condition of the plant, who, if the plant is maintained as an offender against the provisions of the ordinance, may cause suit to be entered, as provided by law, against any and all persons in charge who are violating the ordinance.

The ordinance further provides as follows:

> All accidents to furnaces or smoke-preventing devices in use * * * shall be reported within seventy-two (72) hours to the chief smoke inspector, giving the nature of the accident and the time required to repair the same. Failure to make such report shall constitute a violation of this ordinance.

It is specified that for determining the density of smoke Ringelmann's No. 3 shall be considered dense gray and Ringelmann's No. 4 dense black.[a]

Portland, Oreg.—The city has a section in the general code prohibiting the emission of dense smoke, but has no smoke inspector. No organized or systematic smoke-abatement efforts are being carried on. The need for such work, however, is not great on account of the almost exclusive use of oil fuel in large plants and of wood in smaller plants.

Providence, R. I.—By an act of the General Assembly of Rhode Island the "emission of dense or thick black or gray smoke" from any smokestack or chimney "for a longer period than five minutes at any one time within any city of the State having a population of 150,000 or more, shall be deemed and is hereby declared to be, a public nuisance: *Provided*, That nothing in the act shall be construed as applied to chimneys of buildings used exclusively for private residences, or to locomotives during the time of starting and feeding fires therein while in roundhouses or roundhouse yards."

The defect of this enactment was pointed out by the mayor of Providence, in a public address given over a year ago, when he said: "Since these measures were adopted an improvement has been noted, but complaints are still being made, and in most instances they appear to be reasonable. Our present law on the subject permits the emission of black smoke for five minutes at one time without limiting the frequency of these periods."

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[a] See p. 27.

Rochester, N. Y.—The Rochester smoke ordinance establishes a color scale about 30 per cent black, to be used in determining the darkness of smoke emitted, and prohibits the emission of smoke of greater density, except as quoted below:

> It is forbidden and hereby declared to be unlawful to suffer or permit the escape of smoke from any fire not in motion or fire banked or in a state of rest, or from any burning or active fire through a stationary stack, flue, or chimney of a color darker than said scale: *Provided, however,* That the provisions of this ordinance shall not apply to the escape of smoke from any stationary stack, flue, or chimney for a period of not to exceed five minutes whenever the successful operation and management of any fire necessarily requires such escape of smoke, but such escape of smoke shall not be permitted or allowed for such period more often than once in four consecutive hours.

Smoke darker than the scale mentioned must not be emitted "from any locomotive or canal steam craft standing with banked fires or engaged in shifting or moving within the city limits, * * * or for a period of more than 10 minutes from any locomotive or canal steam craft whose fires may be in preparation for starting, but such escape of smoke shall not be permitted or allowed for such period of time more often than once in 24 consecutive hours * * *." None of these provisions relating to locomotives or boats applies to a locomotive or canal steam craft in transit through or across the city from some point outside the city, or entering or departing therefrom, if such locomotive or canal steam craft does not stop within the city for five consecutive minutes or for periods amounting to more than five minutes. The provisions of the smoke ordinance do not apply between the hours of 5 a. m. and 7.30 a. m.

San Francisco, Cal.—The almost exclusive use of oil fuel in San Francisco makes possible, under nearly all conditions, the generation of heat or power without the emission of dense smoke. At the present time San Francisco has no smoke ordinance and there is no organized effort toward smoke abatement.

Seattle, Wash.—The conditions in Seattle are practically similar to those at San Francisco, as the use of oil fuel is becoming more and more general.

St. Louis, Mo.—A bill has recently been introduced in the municipal assembly with the idea of making certain changes in the present smoke ordinance, which was approved March 12, 1902. This ordinance prohibits the emission of any dense smoke within the city, but provides that "in any suit or proceeding under this ordinance it shall be a good defense if the person charged with the violation thereof shall show to the satisfaction of the jury or court trying the facts that there is no known practicable device, appliance, means, or method by application of which to his building, establishment, or premises the emission or discharge of the smoke complained of in that proceeding could have been prevented."

A smoke-abatement department was created by the ordinance and for some years the work was carried on by that department. About two years ago the work was transferred and put under the direction of the inspector of boilers and elevators, the smoke-abatement department being abolished. Two civic organizations, the civic league and the women's organization for smoke abatement, are supplementing the work of the city inspectors, the women taking an active part in the efforts to secure a strict enforcement of the ordinance.

St. Paul, Minn.—The St. Paul smoke ordinance simply prohibits the emission of dense smoke from any smokestack or chimney and specifies the penalty for violating the provisions of the ordinance.

Washington, D. C.—The escape of dense black or gray smoke or cinders from any stack or chimney in Washington, except those of buildings used exclusively for private residence purposes, is prohibited. Because of the small number of manufacturing plants in the city, the extensive use of anthracite or low-volatile bituminous coals, and the vigilance of the inspectors, there is little smoke in Washington.

NECESSITY OF SMOKE ORDINANCES IN CITIES.

In the foregoing pages has been given a brief statement concerning the work of smoke abatement in some of the more important cities of the country. As the most active and effective efforts are being made in the cities mentioned, each of which has some form of ordinance to regulate the production and emission of dense smoke, an ordinance of proper form would seem necessary if further progress in smoke abatement is to be made. The time may come when public sentiment against permitting the escape of dense smoke will be so strong that every plant owner or operator will feel obliged to prevent such escape of smoke, regardless of the existence of an ordinance or of his own personal feelings or inclinations. So far as the writer knows, such a condition prevails to-day in no city in the United States. Just as soon as each individual realizes that it is not only his duty but that it will work to his own benefit to cooperate in that which will result in the greatest good to all, just so soon will the necessity for a smoke ordinance disappear. In the meantime, however, or until the present methods of burning bituminous coal are radically changed, such a necessity will exist in those localities where large quantities of such coal are consumed.

THE FUNCTION OF A CITY SMOKE ORDINANCE.

Although the passage of a proper ordinance is not, by any means, the solution of the smoke-abatement problem, it is, however, one of the most important steps, and a clear realization of the function of such a statute is therefore essential.

In order to make easier and more certain its enforcement, the ordinance should state definitely what density of smoke is permissible and what density shall not be emitted. Some practical standard of comparison by which the density of the smoke may be determined should be specified. A few of the cities have adopted for this purpose a piece of glass of a certain color and density, and the ordinances in these cities specify that smoke of darker color or of greater density than that of a certain number of thicknesses of this "standard" glass is prohibited. When this method of comparison is used the observer, by looking through the glass with one eye and through or at the smoke with the other, determines whether the glass or the smoke cuts off the greater per cent of the light from the sky.

Other cities use as a standard a chart made by laying out on a white card black lines of specified width at right angles to each other and with a given spacing. The chart is placed in line with the stack with which it is to be compared and at such a distance from the observer's eye that the ruled-line area appears to be of a uniform shade or color. The smoke observed must not be darker than the chart. A large proportion of the cities simply prohibit the emission of "dense" gray or black smoke and do not further define the word "dense." Obviously, an ordinance so formulated leaves open for argument the question as to what is dense smoke, and conviction for violation will for that reason be more difficult.

One objection to the use of the colored glass as a standard is the necessity of using some special device or some glass that has been tested. Comparatively few people would be supplied with such a device or such glass, whereas anyone could prepare according to proper directions the chart described, or such charts could be printed at small expense and distributed gratuitously or sold for a nominal sum. The Ringelmann smoke chart[a] previously mentioned is extensively used for the purpose of grading the density of smoke and is believed to be the best standard for comparison. The division of this chart into four parts or sections of increasing degrees of density makes possible its use by cities desiring to set different standards for all stacks or various standards for the different classes of furnaces.

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[a] The Ringelmann smoke chart, like the chart standard suggested above, is composed of black-line squares. The Ringelmann chart, however, is divided into four parts or cards, the lines forming the squares being of varying widths on the four cards. Desirable widths and spacings for the lines on each card are given by Professor Ringelmann as follows:

Card 1.—Black lines 1 mm. thick, 10 mm. apart, leaving spaces 9 mm. square.

Card 2.—Lines 2.3 mm. thick, spaces 7.7 mm. square.

Card 3.—Lines 3.7 mm. thick, spaces 6.3 mm. square.

Card 4.—Lines 5.5 mm. thick, spaces 4.5 mm. square.

Card 0, all white, and card 5, all black, are sometimes used, card 0 representing no smoke and card 5 representing smoke 100 per cent dense.

In making observations of smoke proceeding from a chimney the four cards, printed in a horizontal row on one chart, are hung at a point about 50 feet from the observer and as nearly as convenient in line with the chimney. At this distance the lines become invisible, the cards ranging in tint from very light gray to almost black. The observer glances from the smoke coming from the chimney to the cards, determines which card most nearly corresponds with the color of the smoke, and makes a record accordingly, noting the card number and time of observation. The observations are repeated at one-fourth or one-half minute intervals. From these records the smoke density may be determined for each hour or for each day.

Copies of this chart may be obtained from the Bureau of Mines.

In fixing the density of smoke that is to be permitted, the requirements should be representative of the best practice; the standard set should not be an impossible nor an impracticable one, neither should it represent ordinary or poor practice. Since the prime object in making these requirements is to bring about an improvement, the standard should be an improvement over the existing local average, in the determination of which the local conditions must be given thorough consideration. In order that the requirements so fixed may be observed, sufficient provision must, of course, be made for penalizing those who refuse to do so.

Another and larger function of the ordinance is to keep existing plants within the requirements and at the same time to provide for proper supervision of future installations. It is evident that such supervision will in most cases prevent the erection of improperly designed furnaces, chimneys, or breechings. Another result will be the provision of adequate space for furnaces and the proper arrangement of furnaces in this space. Under present conditions it is too often the case that buildings are so designed as to leave insufficient room for the power equipment. Boilers are so placed that they can not be properly cleaned or operated; hence they are forced or additional units are crowded in, and smoke-producing conditions result. It is therefore important that the situation of the boiler plant and the providing of adequate space for it should receive consideration no less than the proper design of the furnaces. Obviously, to accomplish these ends, persistent and systematic as well as scientifically correct methods must be adopted. In other words, organization is necessary, and the ordinance should specify not only how the work is to be organized, but also the necessary qualifications of those who are to be appointed to carry it on. Satisfactory progress will seldom be made unless the organization is such that certain officials or employees give their entire attention to the work of smoke abatement and are held responsible for the results produced.

If the installation of improperly designed furnaces is prevented, the policing duties of the smoke inspectors will eventually be reduced to a minimum. The advisability of making this sort of provision is clearly shown in nearly any one of the cities where this protective work is not done, by the fact that some of the newest plants have been so constructed that dense smoke is emitted a large part of the time, even though the firing may be done with a fair degree of care and intelligence. The smoke ordinance should therefore require that plans and specifications for all construction work on furnaces be submitted to the smoke inspector and be approved by him before work is started. If this protective feature is to be included, the smoke inspector must be an engineer, qualified by technical training and experience for the duties of the office, and the ordinance should specify that these qualifications are required.

It may at first appear that if the smoke inspector is to be given the power to decide what furnaces may be installed and what shall be forbidden, the owners or operators should not be held liable for smoke emitted from furnaces constructed according to approved plans. The adoption of any such provision for immunity, however, would release the operator from all responsibility for the way in which the fires were handled. Practically every furnace will produce smoke if improperly handled; hence the operator must be held responsible for the way in which the stoking is done. The inspection of drawings is provided for, not with the idea that the smoke inspector shall design plants for the owners, but rather that he may withhold his approval of plans for work that is known to be improperly designed.

ESSENTIAL FEATURES OF A SMOKE ORDINANCE.

If the number of defective or ineffective smoke ordinances, the number of revisions of this class of city statutes, or the number of inquiries received by the Bureau of Mines may be considered as indicative, there is a need for more technically advised legislation and for more information along these lines. The exact form that the ordinance for any particular city should take can be decided upon only after a study has been made of the existing local conditions. Experience has shown, however, that certain features are desirable and that certain others are undesirable, and in the comment on the city ordinances in the preceding portion of this paper some of both the desirable and the undesirable features are noted. There are presented in the following pages two specimen forms for such enactments, one adapted to the average conditions in a city of, say, 200,000 population or over and the other for a city of smaller size. It is not the writer's idea that these forms should be used without change, but they are offered as representing what is believed to be the best practice to-day. If, as such, they prove valuable to city councils, chambers of commerce, or other city organizations as guides for framing new ordinances, they will have served their purpose.

LARGE CITY.

A form of ordinance proposed for a city of over 200,000 inhabitants is as follows:

Proposed form of smoke ordinance for a large city.

An ordinance providing for smoke inspection and abatement in the city of ——————.

The city council of the city of —————— do ordain as follows:

SECTION 1. There is hereby created a department of smoke inspection, the head of which shall be known as the smoke inspector.

SEC. 2. The smoke inspector shall be appointed by the mayor by and with the advice of the city council and shall perform the duties of his office until removed from office or until his successor is appointed.

SEC. 3. The person so appointed shall be a mechanical engineer qualified by technical training and experience in the theory and practice of the construction and operation of steam boilers and furnaces; also in the theory and practice of smoke abatement and prevention.

SEC. 4. The smoke inspector shall, before entering upon the duties of his office, execute a bond to the city of ——— in the sum of ——— thousand dollars ($———) with sureties approved by the mayor and conditioned upon the faithful performance of his duties.

SEC. 5. The salary of the smoke inspector shall be ——— dollars ($———) per annum.

SEC. 6. There is hereby created the office of assistant chief smoke inspector, who shall be appointed by the smoke inspector as provided by law.

SEC. 7. The person so appointed shall possess the same qualifications as those specified for the smoke inspector.

SEC. 8. The assistant chief smoke inspector shall, before entering upon the duties of his office, execute a bond to the city of ——— in the sum of ——— dollars ($———) with sureties approved by the mayor and conditioned upon the faithful performance of his duties.

SEC. 9. The salary of the assistant chief smoke inspector shall be ——— dollars ($———) per annum.

SEC. 10. There shall be as many deputy smoke inspectors, assistant smoke inspectors, clerks, and stenographers as shall be provided by the city council, their compenation shall be fixed by the city council, and they shall be appointed by the smoke inspector, as provided by law.

SEC. 11. The city council shall appoint a smoke-abatement commission composed of seven representative citizens, who shall act as advisers to the mayor and to the smoke inspector upon matters pertaining to the organization or the conduct of the department, or both. The smoke inspector shall at all times receive and place and keep on file all suggestions, recommendations, advice, or other communications that may be submitted to him in writing by the smoke-abatement commission.

SEC. 12. The smoke-abatement commission may name an advisory board of mechanical engineers, which shall consist of three consulting engineers of recognized ability and integrity, who have had experience in the installation and operation of steam power and heating plants. This board shall act as advisers on engineering questions to the smoke-abatement commission, to the smoke inspector, and to the members of the department. Meetings of the advisory board may be called at any time by the smoke-abatement commission or by the smoke inspector. Members of the advisory board shall receive for their services the sum of ——— dollars ($—) for each regularly called meeting attended.

SEC. 13. No work shall be done upon the erection of any new plant, or on the reconstruction of any old plant for the production of power or heat, or on the erection or reconstruction of any part thereof, except as hereinafter specified, until plans and specifications for such erection or reconstruction shall have been submitted to and approved by the smoke inspector, and a permit issued by him for the prosecution of such work. These plans and specifications shall show not only the nature and extent of the proposed construction work, but also the amount of power or heat to be supplied by such plant and all appurtenances thereto. They shall also show that adequate space has been provided for the installation of equipment, so that it may be properly operated, and shall indicate all provisions made for the purpose of obtaining complete combustion of the fuel to be used and for the purpose of preventing smoke. Said plans and specifications shall also contain a statement of the kind of fuel to be used, including the commercial size of coal when such fuel is specified; said plans and specifications shall also show that the room or apartment in which such plant is to be located is provided with doors, windows, or other means of ventilation sufficient to prevent the temperature of any room or apartment wherein such steam plant or apparatus is to be used from rising to a point higher than 120° Fahrenheit, and sufficient also to provide that the atmosphere of any such room or apartment may be entirely renewed every ten minutes. Upon the approval of said plans and specifications, a duplicate set of which shall be left on file in the smoke inspector's office, and upon payment of the fees hereinafter provided, a permit shall be issued for the erection or reconstruction of such plant. Upon the issuance of such permit the smoke inspector shall then notify the superintendent of building inspection, whose duty it shall then be to see that the work for which the permit has been granted is carried out in accordance with the plans and specifications, with especial reference to the amount of space used, the size and construction of the chimney or chimneys used, the provisions for the prevention of smoke, and the provisions for ventilation and for maintenance of the proper temperature in the engine and boiler rooms.

SEC. 14. It shall be unlawful for any person to use any new or reconstructed plant for the production of heat or power, until he shall have first procured from the smoke inspector a certificate stating that the plant is so constructed that it will do the work required, and that it can be so managed that no dense smoke will be emitted from the chimney connected to the furnace or firebox.

SEC. 15. No owner or operator shall alter or repair any plant for the production of heat or power, or any part thereof, which alteration, change, or installation shall affect the method or efficiency of preventing smoke, without first submitting plans and specifications to the smoke inspector and obtaining a permit therefor; provided, however, that minor necessary or emergency repairs that do not increase the capacity of such plant, or that do not involve any alterations in the method or efficiency of smoke prevention may be made by or under the engineer in charge of said plant without a permit. Any person who shall violate this section shall be liable to a fine of $25 for each day upon which he shall prosecute such alteration, change, or installation without a permit, and each day's violation shall constitute a separate offense.

SEC. 16. The fees for the inspection of plans and specifications, for the issuing of permits, and for the inspection of plants and issuing of certificates shall be as follows:

For inspecting plans of new plants and of plants about to be reconstructed, $2.

For inspecting plans for repairs and alterations, $1.

For examining a plant after its erection or reconstruction and before its operation and maintenance, $2.

The fee paid for the inspection or examination shall include the issuing of a permit or certificate, in case such permit or certificate is granted.

SEC. 17. The emission of dense smoke within the city from the smokestack of any locomotive, steamboat, or steam tug for a period of more than one minute, except for a period or periods aggregating not to exceed 10 minutes in any one hour during which period or periods the firebox is being cleaned or a new fire is being built therein, is hereby declared a nuisance: *Provided*, That the fire engines or the fire boats of the city fire department, or both of them, shall be exempt from these restrictions.

The emission of dense smoke within the city from the smokestack of any steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises, except for a period or periods aggregating not to exceed six minutes in any one hour during which period or periods the firebox is being cleaned or a new fire is being built therein, is hereby declared a nuisance.

Any nuisance such as the above-specified may be summarily abated by the smoke inspector, or by anyone whom he may duly authorise for the purpose, and such abatement may be in addition to the fine hereinafter provided.

Any person or persons, or corporation, owning, operating, or in charge or control of any locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or of any building or premises, who shall cause or permit the emission of dense smoke within the city, in contravention of the provisions of this section, from the smokestack of any locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestock or chimney of any building or premises so owned, controlled, or in charge of him, her, or them, shall be deemed guilty of a violation of the ordinance, and upon conviction thereof shall be fined not less than ten dollars ($10) nor more than one hundred dollars ($100) for each offense; and each day of such emission of dense smoke shall constitute a separate offense.

For the purpose of grading the density of smoke, the Ringelmann smoke chart, as published and used by the Federal Bureau of Mines, shall be the standard of comparison. Smoke shall be considered "dense" when it is of a greater density than No. 3 of the chart.

SEC. 18. The provisions of sections 13, 14, 15, and 17 shall not apply to detached private residences, nor to buildings used exclusively for private residence purposes, in which the number of families occupying apartments shall be less than five.

SEC. 19. Prosecutions for all violations of this ordinance shall be instituted by the smoke inspector and shall be prosecuted in the name of the city of ———.

The issuance and delivery by the smoke inspector of any permit or certificate for the construction or reconstruction of, or any permit for the alteration or repair of any plant or chimney connected with a plant shall not be held to exempt any person or corporation to whom such permit or certificate has been issued or delivered, or who is in possession of any such permit or certificate, from prosecution on account of the emission or issuance of dense smoke caused or permitted by such person or corporation.

SEC. 20. Any person who shall violate any of the provisions of this ordinance, except as otherwise provided, shall be fined not less than ——— dollars ($—) nor more than ——— dollars ($—) for each offense.

SEC. 21. The city shall provide such instruments, books, papers, and equipment as shall be necessary for the proper performance of the duties of the members of the department. The smoke inspector shall have charge of such instruments, books, paper, and equipment, and shall deliver the same to his successor in office.

SEC. 22. The smoke inspector shall cause to be kept in his office a complete record of all plans submitted, of all permits issued, of all examinations of plants made by members of the department, and of all certificates issued. He shall also cause to be kept a record of all stacks observed and of the smoke observations for any stack that is found to exceed the allowable time limit for dense smoke.

SEC. 23. The smoke inspector shall make an annual report of the work of his department to the mayor and to the city council on or before ————, and at such other times as he may be required by the city council.

SEC. 24. If any person acting on behalf of the city under the provisions of the ordinance shall take or receive any money or any valuable thing for the purpose of deceiving any person or persons, or for the purpose of favoring any person or persons, he shall be fined ——— dollars ($——) for each offense and shall be dismissed from the service, and any bond he may have made shall be forfeited; or if the inspector shall issue any certificate of inspection before the department shall have thoroughly examined and inspected the furnace, device, or apparatus as certified, he shall be fined ——— dollars ($——) for each offense.

MEDIUM-SIZE CITY.

It is recognized that the smaller cities can not maintain as extensive an organization to carry on the smoke-abatement work, and that it is usually not practicable to make regulations so stringent therein as is advisable in the larger cities. In other words, the smaller city must adopt somewhat different methods in this work than are practicable for the larger city. A form of ordinance suitable for the average conditions in cities of 50,000 to 200,000 inhabitants has therefore been drafted and is as follows:

Proposed form of smoke ordinance for a medium-size city.

An ordinance providing for smoke inspection and abatement in the city of ————.

The city council of the city of ———— do ordain as follows:

SECTION 1. There is hereby created the office of smoke inspector, the compensation and duties connected therewith to be as hereinafter specified.

SEC. 2. The smoke inspector shall be appointed by the mayor, by and with the advice of the city council, and shall perform the duties of his office until removed from office or until his successor is appointed.

SEC. 3. The person so appointed shall be an engineer qualified by training and experience in the theory and practice of the construction of steam boilers and furnaces, also in the theory and practice of smoke abatement and prevention.

SEC. 4. The salary of the smoke inspector shall be ——— dollars ($———) per annum.

SEC. 5. There shall be as many deputy smoke inspectors, assistant smoke inspectors, clerks, and stenographers as shall be provided by the city council; their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector as provided by law (or by the mayor, by and with the advice of the city council).

SEC. 6. The city council shall appoint a citizens' smoke-abatement committee composed of seven (7) representative members, who shall act as advisors to the mayor and to the smoke inspector upon matters pertaining to the organization or the conduct of the smoke-abatement work, or both. The smoke inspector shall at all times receive and place and keep on file all suggestions, recommendations, advice, or other communications that may be submitted to him in writing by the said committee.

SEC. 7. The citizens' smoke-abatement committee may procure the services of a consulting mechanical engineer of recognized ability who has had exprience in the installation and operation of steam power and heating plants, and particularly in the prevention of smoke in such plants, to advise the smoke inspector and the committee upon engineering problems in connection with the smoke-abatement work whenever such advice is required; provided, however, that the total expense incurred for such consulting advice shall not exceed the sum allowed for such purpose by the city council.

SEC. 8. It shall be unlawful for the owner, lessee, or operator of any existing plant, or of any plant about to be constructed, for the production of power or heat, to proceed with the construction, reconstruction, or alteration of such plant until plans and specifications for such work shall have been submitted to the smoke inspector, approved by him, and a permit for the prosecution of such work issued. These plans and specifications shall show the nature and extent of the work to be done and the amount of power or heat to be supplied by such plant. Said plans and specifications shall also contain a statement of the kind of fuel to be used and shall show all provisions made for the purpose of obtaining complete combustion of the fuel to be used and for the purpose of preventing smoke. They shall also show that the space to be occupied by the plant and the location of the equipment therein will not prevent the proper operation of said equipment. Said plans and specifications shall also show that the room or apartment in which such plant is to be located is provided with doors, windows, or other means of ventilation sufficient to prevent the temperature in said room or apartment from rising to a point higher than 120° Fahrenheit, and sufficient also to provide that the air in said room or apartment may be entirely renewed every ten minutes. Upon the approval of such plans a duplicate copy shall be left with the smoke inspector, who shall then notify the building inspector, and it shall be the duty of said building inspector to see that the work is done in accordance with the plans and specifications. The foregoing provisions of this section shall not apply to the steam plants in buildings used exclusively for private residence purposes in which the number of families occupying apartments shall be less than five, nor to minor necessary or emergency alterations or repairs in any other plants, which alterations or repairs do not increase the capacity of said plants, or which do not involve any substantial alteration in structure, and which do not involve any alteration in the method or efficiency of smoke prevention.

Any person who shall violate this section shall be liable to a fine of twenty-five dollars ($25) for each day upon which he shall prosecute such alteration, change, or installation without a permit, and each day's violation shall constitute a separate offense.

Sec. 9. A fee of one dollar ($1) shall be charged for the inspection of plans and specifications for the erection, reconstruction, or alteration of any plant, this fee to include the issuing of a permit, in case such permit is granted.

Sec. 10. The emission of dense smoke within the city from the smokestack of any locomotive, steamboat, or steam tug for a period of more than seventy-five (75) seconds, except for a period or periods aggregating not to exceed 12 minutes in any one hour, during which period or periods the firebox is being cleaned or a new fire being built therein, is hereby declard a nuisance: *Provided*, That the fire engines or fire boats of the city fire department, or both of them, shall be exempt from these restrictions.

The emission of dense smoke within the city from the smokestack of any steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises, except for a period or periods aggregating not to exceed nine minutes in any one hour, during which period or periods the fire box is being cleaned or a new fire is being built therein, is hereby declared a nuisance.

Any nuisance such as the above specified may be summarily abated by the smoke inspector, or by anyone whom he may duly authorize for the purpose, and such abatement may be in addition to the fine hereinafter provided.

Any person or persons, or corporation owning, operating, or in charge or control of any locomotive, steamboat, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or of any building or premises, who shall cause or permit the emission of dense smoke within the city, in contravention of the provisions of this section, from the smokestack of any such locomotive, steamboat, steam tug, steam roller, steam pile driver, steam derrick, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises so owned, controlled, or in charge of him, her, or them, shall be deemed guilty of a violation of this ordinance, and upon conviction thereof shall be fined not less than ten dollars ($10) nor more than one hundred dollars ($100) for each offense; and each day of such emission of dense smoke shall constitute a separate offense.

For the purpose of grading the density of smoke the Ringelmann smoke chart, as published and used by the Federal Bureau of Mines, shall be the standard of comparison. Smoke shall be considered "dense" when it is of greater density than No. 3 of the chart.

The provisions of this section shall not apply to detached private residences, nor to buildings used exclusively for private residence purposes, in which the number of families occupying apartments shall be less than five.

SEC. 11. Prosecutions for all violations of this ordinance shall be instituted by the smoke inspector and shall be prosecuted in the name of the city of ————.

The issuance and the delivery by the smoke inspector of any permit for the construction, reconstruction, alteration, or repair of any plant or chimney connected with a plant, shall not be held to exempt any person or corporation to whom such permit has been issued or delivered, or who is in possession of any such permit, from prosecution on account of the emission or issuance of dense smoke caused or permitted by such person or corporation.

SEC. 12. The city shall provide such instruments, books, papers, and equipment as shall be necessary for the proper prosecution of the smoke-abatement work. The smoke inspector shall have charge of such instruments, books, papers, and equipment, and shall deliver the same to his successor in office.

SEC. 13. The smoke inspector shall cause to be kept in his office a complete record of all plans submitted and of all permits issued. He shall also cause to be kept a record of all stacks observed and of the smoke observations from any stack that is found to exceed the allowable time limit for dense smoke.

SEC. 14. The smoke inspector shall make a report of his work or the work done under his direction to the mayor and city council annually, on or before ————, and at other times as often as required by the city council.

SEC. 15. If any person acting on behalf of the city under the provisions of this ordinance shall take or receive any money or any valuable thing for the purpose of favoring any person or persons, he shall be fined ——— dollars ($——) for each offense and shall be dismissed from the service; or if the inspector shall issue any permit as mentioned in section 8 of this ordinance, without thoroughly examining the plans and specifications for the work for which the permit is issued, he shall be fined ——— dollars ($——) for each offense.

SMALL CITY.

The problem in the city of, say, 20,000 population will usually require a different method of attack than has been outlined for either the large or the medium-sized city. A small city has comparatively few new boiler plants, reconstructions, or alterations in the course of a year, so that the policing phase becomes of major importance. However, the small city ought to protect itself and its manufacturers from the installation of improperly designed furnaces and thereby save heavy expenditures for reconstruction in later years. The board of trade or a similar civic organization of such a city can authorize a committee to obtain information concerning furnace designs or methods of operation developed in other cities, or to inform themselves so that they may be able to direct those interested to competent advisors on the subject of smoke prevention. With a strong public sentiment to supplement its efforts such a civic organization should be able to accomplish much good in the smaller cities that can afford no organized municipal effort toward smoke abatement.

ENFORCEMENT OF SMOKE ORDINANCES.

Undoubtedly, the chief reason why our cities have not made more rapid progress toward smoke abatement has been the failure of those intrusted with the enforcement of the smoke ordinances properly to perform their duties. In many cities where there are ordinances prohibiting or restricting the emission of dense smoke, little report is ever heard of any effort to enforce compliance with their provisions. Nevertheless, one of the first arguments raised by those who are opposing the enactment of such legislation in any city is that they will be continually annoyed by an overbearing inspector. If, as is usually the case, there appears to be laxity in enforcing the ordinance, blame ordinarily attaches to the smoke inspector, whereas to others may belong the greater share of responsibility. It is believed that frequently the real trouble lies in the fact that wrong methods of enforcement are adopted.

Public sentiment is just as necessary for the successful enforcement of smoke ordinances as for the enforcement of any other class of laws or ordinances. Compliance with such enactments can be had and will be demanded by public officials only when required by public opinion, but it is essential for the accomplishment of the best results that the force of such opinion be used in the most effective manner—it should be manifested in constructive effort and not in mere fault-finding. A few cities have considered this matter of such importance that they have provided in their smoke ordinances for stimulating and making the best use of these constructive activities by having a smoke-abatement committee or commission composed of representative citizens to advise with the mayor and the inspector. If the members of such a committee are carefully selected their cooperation should enable the city department to accomplish much more than would otherwise be possible. The committee will, if so selected, act as a balance wheel for the department by preventing inactivity or overactivity.

In this connection the value of the advice of such a committee in assisting the inspector to determine the proper policy to be followed in any particular instance or under any given conditions should not be overlooked. Furthermore, the announcement to the offender of the procedure proposed will frequently be more agreeably received from the chairman or other members of the committee than from the inspector. The prevention of dense smoke in some plants may be possible only after radical changes are made, and in such a case the owner or operator will usually be more inclined to yield to the urging of the committee than he would to that of a city official. The more the plant owners and operators feel that there is a spirit of cooperation being manifested toward them the easier can compliance with the ordinance be obtained.

At the same time, however, firmness and impartiality in carrying out the spirit of the law are equally essential. Promises and excuses are easily made, and some owners are inclined to stave off for as long a time as possible the alterations, reconstruction, or extra attention necessary to enable them to obey the law. The imposing of a fine for excessive smoke will usually have the desired effect on such offenders, but recourse to the courts should be had only when argument and persuasion prove futile.

If the city is large enough to be able to employ a technically trained expert as smoke inspector and to provide for expert consulting advice for him or for the smoke-abatement committee or commission, money will probably be saved to the business interests of the city and more rapid progress made in the elimination of smoke by so doing. Smaller cities that are unable to appropriate sufficient funds for such a course may, in a measure, accomplish the same end by furnishing to plant owners, through their smoke-abatement committees or their chambers of commerce or boards of trade, information relative to, and possibly drawings of, satisfactory installations of any particular type of boiler. Through these same channels they may supply the names of engineers who are capable of advising the owner on difficult engineering problems that may be involved in the building, reconstructing, or altering of plants.

The important point is that the plant owner or operator shall realize the necessity of considering smoke prevention whenever furnace-construction work is to be done, and shall thus be saved the expense of tearing out and reconstructing such furnaces.

CONCLUSION.

It is not intended that the reader will gain from a perusal of the preceding pages the impression that the abatement of coal smoke in any city is a simple problem, or that it can be accomplished in a short time. The effort has rather been to point out wherein some of the efforts toward this end have been misdirected and to indicate what are believed to be better methods of attack. The real reason that more has not been accomplished up to the present time in many of our cities is that, through ignorance or indifference, money and efforts have been wrongly applied. The complete elimination of the smoke nuisance will not be possible in such cities until improved and radically different methods of utilizing the fuel are adopted. With properly designed and well-operated furnaces a great reduction in the amount of smoke is to-day not only possible but is necessary.

APPENDIX.

For the information of persons who wish to know the exact phraseology of some of the smoke-abatement ordinances mentioned in this bulletin, especially of those ordinances that contain features of particular interest, the smoke-abatement ordinances of the cities of Chicago, Pittsburgh, Des Moines, Milwaukee, and Los Angeles are printed at length, as well as the State act that applies to the city of Boston.

The Chicago ordinance is perhaps the most comprehensive and most complete of those in effect in the large cities of the United States. Its requirements apply particularly to the needs of a great industrial center where coals high in volatile matter are the chief available fuel. The ordinance is as follows:

Be it ordained by the city council of the city of Chicago:

SECTION 1. There is hereby established a department of smoke inspection, the head of which shall be known as the smoke inspector.

SEC. 2. The smoke inspector shall be appointed by the mayor by and with the advice of the city council.

SEC. 3. The person so appointed shall be a mechanical engineer, qualified by technical training and experience in the theory and practice of the construction and operation of steam boilers and furnaces and also in the theory and practice of smoke abatement and prevention.

SEC. 4. The smoke inspector, before entering upon the duties of his office, shall execute a bond to the city of Chicago in the sum of $10,000, with sureties to be approved by the mayor, conditioned upon the faithful performance of the duties of his office.

SEC. 5. The salary of the smoke inspector shall be $4,000 per annum.

SEC. 6. There is hereby created the office of chief assistant smoke inspector, who shall be appointed by the smoke inspector as provided by law.

SEC. 7. The qualifications of the chief assistant smoke inspector shall be the same as the qualifications herein provided for the smoke inspector.

SEC. 8. The chief assistant smoke inspector shall, before entering upon the duties of his office, execute a bond to the city of Chicago in the sum of $5,000, with sureties to be approved by the mayor, conditioned upon the faithful performance of the duties of his office.

SEC. 9. The salary of the chief assistant smoke inspector shall be $3,000 per annum.

SEC. 10. There shall be as many deputy smoke inspectors as shall be provided for by the city council; their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector in the manner provided by law.

SEC. 11. There shall be as many assistant smoke inspectors as shall be provided by the city council; their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector in the manner provided by law.

SEC. 12. There shall be as many clerks and stenographers assigned to this department as shall be provided by the city council; their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector in the manner provided by law.

SEC. 13. The mayor may in his discretion appoint a smoke-abatement commission composed of eight members, who shall act as advisers to the mayor in the organization of the department and as advisers to the smoke inspector in the conduct of the department. The smoke inspector shall at all times receive, place, and keep on file in his office any suggestion, recommendation, advice, or other communication which may be presented to him in writing by the smoke-abatement commission. The smoke-abatement commission may name an advisory board of mechanical engineers which shall consist of three consulting engineers of recognized ability and integrity, who have had experience in the installation and conduct of power and heating plants. This board shall act as advisers on engineering questions to the smoke-abatement commission and to the smoke inspector and to the members of the department. Meetings of the advisory board of mechanical engineers may be called at any time either by the smoke-abatement commission or by the smoke inspector. Members of the advisory board of mechanical engineers shall receive as their compensation the sum of $10 for each member for each regularly called meeting attended.

SEC. 14. No new plants or any reconstruction of any old plants for producing power and heat, or either of them, or any new chimney connected with a steam plant shall be erected or maintained in the city until plans and specifications of the same have been filed in the office of and approved by the smoke inspector and a permit issued by him for such erection, reconstruction, or maintenance. Plans and specifications to be filed with the smoke inspector shall show the amount of work and the amount of heating to be done by such plant and all appurtenances thereto, including all provisions made for the purpose of securing complete combustion of the fuel to be used and for the purpose of preventing smoke; said plans and specifications shall also contain a statement of the kind of fuel proposed to be used, and said plans and specifications shall also show that the room or apartment in which such plant shall be located is provided with doors, windows, air shafts, fans, and other means of ventilation sufficient to prevent the temperature of such room, apartment, basement, or other portion of such building wherein such steam plant or apparatus is to be used from rising to a point higher than 120° F., and sufficient also to provide that the atmosphere of any such apartment wherein such apparatus may be located may be entirely renewed every 10 minutes. Upon the approval of such plans and specifications, a duplicate set of which shall be left on file in said office, and upon the payment of the fees as hereinafter provided, the smoke inspector shall issue a permit for the reconstruction, erection, or maintenance of such plant. As soon as the smoke inspector has examined the plans and specifications submitted and has issued a permit as above provided, he shall then notify the commissioner of buildings to see that the execution of the work permitted is carried out in conformity with the plans and specifications, with special reference to the amount of space used, the size and construction of the chimney or chimneys used, the provisions for the prevention of smoke, and the provisions for ventilation, and for the proper temperature in the engine and boiler rooms.

SEC. 15. It shall be unlawful for any person to use any new or reconstructed plant for the production and generation of heat and power, or either of them, until he shall have first procured a certificate from the smoke inspector that the plant is so constructed that it will do the work required, and that it can be so managed that no dense smoke shall be emitted from the chimney connected with the furnace or fire box.

SEC. 16. No owner shall alter or repair any chimney or any old furnace or device, which alteration, change, or installation shall affect the method or efficiency of preventing smoke, without first submitting plans and specifications to the smoke inspector and securing a permit therefor: *Provided, however,* That minor necessary or emergency repairs which do not increase the capacity of such plant or which do not involve any substantial alteration in structure, and which do not involve any alteration in the method or efficiency of smoke prevention, may be made by or under the engineer in charge of said plant without a permit. Any person who shall violate this section shall be liable to a fine of $25 for each day upon which he shall prosecute such alteration, change, or installation without a permit, and each day's violation shall constitute a separate offense.

SEC. 17. The emission of dense smoke within the city from the smokestack of any locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises, excepting for a period of six minutes in any one hour, during which the fire box is being cleaned out or a new fire being built therein, is hereby declared to be a nuisance, and may be summarily abated by the smoke inspector, or by anyone whom he may duly authorize for such purpose. Such abatement may be in addition to the fine hereinafter provided. Any person or persons, or corporation, owning, operating, or in charge or control of any locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or of any building or premises, who shall cause or permit the emission of dense smoke, within the city, from the smokestack or chimney of any such locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises so owned, controlled, or in charge of him, her, or them, except for a period of six minutes in any one hour, during which the fire box is being cleaned out or a new fire built therein, shall be deemed guilty of a violation of this ordinance, and upon conviction thereof shall be fined not less than $10 nor more than $100 for each offense, and each day of such emission of dense smoke shall constitute a separate offense.

SEC. 18. The fees for the inspection of plans and issuing of permits for the inspection of plants and issuing of certificates shall be as follows:

For inspecting plans of new plants and plants about to be reconstructed, $2.

For inspecting plans for repairs and alterations, $1.

For examining a plant after its erection or reconstruction and before its operation and maintenance, $3.

The fee paid for the inspection or examination shall include the issuing of a permit or certificate, in case such permit or certificate is granted.

The smoke inspector may, and he is hereby, directed and instructed to remit all inspection or examination fees charged, or that hereafter may be charged, against any and all charitable, religious, and educational institutions when the furnace or other device or apparatus inspected is located in or upon premises used and occupied exclusively by such charitable, religious, or educational institutions: *Provided,* That such charitable, religious, or educational institution is not conducted or carried on for private gain or profit: *And provided further,* That the smoke inspector may require every application for the remission of such fees to be verified by the affidavit of one or more taxpayers of the city.

SEC. 19. Prosecutions for all violations of this ordinance shall be instituted by the smoke inspector and shall be prosecuted in the name of the city of Chicago.

The issuance and delivery by the smoke inspector of any permit or certificate for the construction or reconstruction, or any permit for the alteration or repair of any plant or chimney connected with a plant, shall not be held to exempt any person or corporation to whom any such permit has been issued or delivered, or who is in possession of any such permit, from prosecution on account of the emission or issuance of dense smoke caused or permitted by any such person or corporation.

SEC. 20. Any person who shall violate any of the provisions of this ordinance (except as is herein otherwise provided) shall be fined not less than $25 nor more than $100 for each offense.

SEC. 21. The city shall provide such instruments, books, papers, and equipment as shall be necessary for the proper performance of the duties of the members of the department. The smoke inspector shall have charge of such instruments, books, papers, and equipment, and shall deliver the same to his successor in office.

SEC. 22. The smoke inspector shall cause to be kept in his office a complete record of all plans submitted and of all permits issued and of all examinations of plants made by members of the department and also of all certificates issued.

SEC. 23. The smoke inspector shall make a report of the work of his department to the mayor and city council annually, on or before the 1st day of February, and at other times as often as required by the city council.

SEC. 24. If any person acting on behalf of the city under the provisions of this chapter shall take or receive any money or any valuable thing for the purpose of deceiving or defrauding any person or persons, or for the purpose of favoring any person or persons, or if any inspector shall recommend the issue of any certificate of inspection without having at the time stated thoroughly examined and tested the furnace, device, or apparatus so certified, he shall be fined $100 for each offense.

SEC. 25. Chapter LXIV of the Revised Municipal Code of Chicago of 1905, as amended, so far only as said chapter refers to smoke inspection, is hereby repealed, and the position of chief smoke inspector created by said chapter is hereby abolished.

SEC. 26. This ordinance shall take effect on and after its passage and publication.

The Pittsburgh ordinance applies especially to a large manufacturing city in which many metallurgical plants complicate the problem of smoke abatement. The ordinance, which became effective in October, 1911, reads as follows:

SECTION 1. *Be it ordained and enacted by the city of Pittsburgh, in council assembled, and it is hereby ordained and enacted by the authority of the same,* That no steam-boiler furnace or other furnace, excepting in private residences, mill-heating furnaces, and puddling furnaces, shall be constructed within the corporate limits of the city of Pittsburgh until the owner, agent, or lessee shall first make written application at the office of the chief smoke inspector for a certificate for that purpose and shall furnish a written statement and drawings of the style and dimensions of such boiler or furnace, the height and size of stack or chimney, and the method or device for preventing the emission of dense black or dense gray smoke therefrom for more than eight (8) minutes in any one hour, and the chief smoke inspecor's approval has been obtained: *Provided, however,* That no discrimination shall be exercised for or against any method, including hand firing, which will and does now prevent the emission of dense black or dense gray smoke except for eight (8) minutes in any one hour.

SEC. 2. Every boiler furnace or other furnace used within the corporate limits of the city of Pittsburgh, excepting in private residences, mill-heating furnaces, and puddling furnaces, in which bituminous coal is burned as fuel, shall be so constructed or altered as to prevent the production and emission of dense black or dense gray smoke therefrom, except for eight (8) minutes in any one hour; and no person or persons, associations, or corporation being the owner or lessee, or having control of any such steam boiler or other furnace, shall use or allow the use of any steam boiler or other furnace which shall not be so constructed, or if already constructed at the time of the passage of this ordinance, which shall not be so altered, or the method of stoking be so regulated as to prevent the emission of dense black or dense gray smoke for more than eight (8) minutes in any one hour.

SEC. 3. The issuance and delivery by the smoke inspector of any permit or certificate for the construction or reconstruction, or any permit for the alteration or repair of any plant or chimney connected with a plant, shall not be held to exempt any person or corporation to whom any such permit has been issued or delivered, or who is in possession of any such permit, from prosecution on account of the emission or issuance of dense black or dense gray smoke caused or permitted by any such person or corporation, in violation of the terms of this ordinance.

SEC. 4. It shall be the duty of the deputy smoke inspectors personally to inspect all chimneys, steam-generating plants, and all other furnace apparatus in use, excepting in private residences, mill-heating furnaces, and puddling furnaces, and to make written reports of the same to the chief smoke inspector, who shall keep a permanent record of all essential facts relating thereto. The chief smoke inspector or his deputies shall have authority to inspect and supervise all boilers or furnaces which are subject to the provisions of this ordinance within the corporate limits of the city of Pittsburgh and upon the waters adjacent thereto, where such are within the jurisdiction of the provisions of this ordinance, and shall further have authority to examine and supervise the igniting, stoking, feeding, and attending such boiler or other furnace fires, and for that purpose he or his duly appointed assistants shall also have authority to enter any steam boiler or engine room, or any building from which dense black or dense gray smoke is being emitted, and during the preceding twenty-four hours has been emitted; and any person or persons hindering or obstructing them in the performance of such duty shall be guilty of a violation of this ordinance.

SEC. 5. If the escape of smoke is the dense black or dense gray smoke which is prohibited within the meaning of this ordinance, the chief smoke inspector shall make complaint to the persons so offending, defining the offense. In the event that the cause thereof is unskillful stoking, he shall cause one of his assistants to give proper instructions to correct same and he shall make immediate complaint to the director of the department of public health against any and all such persons violating this ordinance. In the event that said offense is owing to the faulty construction of the furnace, size or height of stack connections, or other engineering details relating to boiler or other furnace construction or connection, he shall make statement of the cause of such offense and report to the owners or operators as to the necessary changes, alterations, or additions to be made; and in such case such time for such alterations or repairs in no instance shall exceed six (6) months. In the event that it should appear from the inspection of the chief smoke inspector that no change or alteration of the furnace, furnace connections, stack, or appurtenances thereto would eradicate said offense, and that said offense is owing to a plant being worked to excess of its normal capacity, or for other organic reason can not be converted by such changes into a plant which is not an offender within the meaning of this ordinance, then he shall report to the owners or operators as above mentioned the conditions of such plant and the required changes or additions necessary therein, so that it may not be operated as an offender. Not more than nine (9) months shall be allowed in which to complete such changes. Notices as above shall be in writing, and at the expiration of the time allowance the chief smoke inspector shall investigate and make report to the director of the department of public health as to the condition of the plant, who, in the event it is maintained as an offender against the provisions of this ordinance, may cause suit to be entered, as provided by law, against any and all persons in charge who are violating this ordinance.

SEC. 6. All accidents to furnaces or smoke-preventing devices in use, excepting in private residences, mill-heating furnaces, and puddling furnaces, shall be reported within seventy-two (72) hours to the chief smoke inspector, giving the nature of the accident and the time required to repair the same. Failure to make such report shall constitute a violation of this ordinance.

SEC. 7. During the first hour in which a new fire is being kindled in or under a cold boiler or other furnace, excepting in private residences, mill-heating furnaces, and puddling furnaces, sixty (60) minutes once a day for the first year, forty-five (45) minutes once a day for the second year, and thirty (30) minutes once a day for the third year, and each and every year thereafter of dense black or dense gray smoke issuing from the stack or chimney thereof will not be a violation of this ordinance; but during each succeeding hour that such boiler or other furnace is in service more than eight (8) minutes of dense black or dense gray smoke issuing from the chimney or stack thereof in any one hour shall be, and the same is, a violation of this ordinance.

SEC. 8. As an official chart to be used by smoke inspectors for determining the density of smoke in the city of Pittsburgh, Ringelmann's smoke scale, as supplied by the United States Geological Survey, shall be used. The third shade in density on said scale shall be known as dense gray, and the fourth shade in density shall be known as dense black.

SEC. 9. The owner or owners, the officers, managers, or agents of any corporation owning, leasing, or occupying, and any person operating or having charge or controlling any furnace, boiler, heating, or power or manufacturing plant, any locomotive, portable engine or boiler, street roller, motor vehicle self-propelled on a public street, steamboat, stationary engine or boiler, or any building or structure of any description emitting dense black or dense gray smoke, or by or from which dense black or dense gray smoke is emitted, except in the cases exempt under the terms of this ordinance and except for the times hereinbefore specified in sections 1, 2, and 7, shall be deemed guilty of violating the provisions of this ordinance, and upon conviction thereof before any alderman or police magistrate he or they or any other person being convicted of violating any of the provisions of this ordinance before any alderman or police magistrate shall be fined not less than ten ($10) dollars nor more than one hundred ($100) dollars, and in default of the payment of said fine and costs shall be committed to the Allegheny County Workhouse for a period not exceeding thirty (30) days for each offense, and each day in which such smoke shall be so emitted shall constitute a separate and distinct offense.

SEC. 10. That any ordinance or part of ordinance conflicting with the provisions of this ordinance be, and the same is hereby, repealed so far as the same affects this ordinance.

The Des Moines ordinance is presented as an example of an ordinance drawn for a relatively small city in which high-volatile coals are burned almost exclusively. It reads as follows:

Be it ordained by the city council of the city of Des Moines:

SECTION 1. The emission of dense smoke from the smokestack of any locomotive or engine, or from the smokestack of any stationary engine, or from the smokestack, chimney, or fireplace of any building or plant anywhere within the city of Des Moines shall be deemed, and is hereby declared, to be a public nuisance and is hereby prohibited except as hereinafter provided.

SEC. 2. The owner or owners of any locomotive engine and the general manager, superintendent, yardmaster, or other officer of any railroad company having charge or control of the operation of any locomotive engine who shall cause, permit, or allow dense smoke to issue or be emitted from the smokestack of any such locomotive engine within the city of Des Moines, except as hereinafter provided, shall be deemed and held guilty of creating a public nuisance and of violating the provisions of this ordinance.

SEC. 3. The owner, lessee, or occupant of any building or plant and the fireman, engineer, or any other person having charge or control of any furnace, fireplace, or stationary engine who shall cause, permit, or allow dense smoke to issue or be emitted from the smokestack, fireplace, or chimney of any such building or plant, or from the smokestack, fireplace, or chimney connected with any such plant, furnace, or stationary engine within the city of Des Moines, except as hereinafter provided, shall be deemed and held guilty of creating a public nuisance and of violating the provisions of this ordinance.

SEC. 4. There is hereby established as a part of the department of public safety a department of smoke inspection, the head of which shall be known as the smoke inspector.

SEC. 5. The smoke inspector shall be appointed by the city council, and the person so appointed shall be qualified by training and experience in the theory and practice of the construction and operation of steam boilers and furnaces in their relation to smoke abatement and the prevention of the emission of dense smoke therefrom. He shall, before entering upon his duties, execute a bond with the city of Des Moines in the sum of $1,000, the sureties to be approved by the city council, conditioned upon the faithful performance of the duties of the office. His salary shall be fixed by the city council.

SEC. 6. The city council shall appoint a smoke-abatement commission, composed of five members, who shall act as advisors to the smoke inspector in the conduct of the department. The smoke inspector shall at all times receive, place, and keep on file in his office all suggestions, recommendations, advice, and other communications which may be presented to him in writing by the smoke-abatement commission.

SEC. 7. No new plants or any reconstruction of old plants for producing power and heat, or either of them, either for sale or manufacturing purposes, or any new chimney, furnace, or fireplace connected with such plant or any steam plant shall be erected or maintained in the city until plans and specifications of the same have been filed in the office of and approved by the smoke inspector, and a permit issued by him for such erection, reconstruction, or maintenance: *Provided*, That in case of controversy as to the sufficiency of such plans and specifications and the provisions made therein for fuel combustion said plans and specifications shall be submitted to the smoke-abatement commission, one of whom shall have had experience in the installation and conduct of power and heating plants. The decision of said board shall be binding upon all parties. Such plans and specifications shall show the amount of work and the amount of heating to be done by such plant and all appurtenances thereto, including all provisions made for the purpose of securing complete combustion of the fuel to be used and for the purpose of preventing smoke and shall also contain a statement of the kind of fuel proposed to be used. Upon the approval of such plans and specifications, a duplicate set of which shall be left on file, and upon the payment of the fees as hereinafter provided the smoke inspector shall issue a permit for the reconstruction, erection, or maintenance of such plant. As soon as the smoke inspector has examined the plans and specifications submitted and has issued a permit as above provided, it shall be the duty of the inspector to see that the execution of the work permitted is carried out in conformity with the plans and specifications with special reference to the amount of space used, and size and construction of chimneys used, and the provisions for the prevention of smoke.

SEC. 8. It shall be unlawful for any person to use any new or reconstructed plant for the production and generation of heat and power, or either of them, either for sale or manufacturing purposes, until he shall have first procured a certificate from the smoke inspector that the plant is so constructed that it will do the work required, and that it can be so managed that no dense smoke shall be emitted from the chimney connected with the furnace or firebox, except as permitted in this ordinance.

SEC. 9. No owner shall alter or repair any chimney, fireplace, or any old furnace or device, which alteration, change, or installation shall affect the method or efficiency of preventing smoke, without first submitting plans and specifications to the smoke inspector and securing a permit therefor. In case of controversy the plans and specifications herein required shall be submitted to the smoke-abatement commission as provided in section 7 hereof: *Provided, however*, That minor necessary or emergency repairs which do not increase the capacity of such plant or which do not involve any substantial alteration in structure and which do not involve any alteration in the method or efficiency of smoke prevention may be made by or under the engineer in charge of said plant without a permit. A violation of this section shall subject the guilty party to a fine of not to exceed $25 for each day upon which he shall prosecute such alterations, change, or installation without a permit, and each day's violation shall constitute a separate offense.

SEC. 10. The fees for the inspection of plans and issuing of permits and for the inspection of plants and issuing of certificates shall be as follows:

For inspecting plans and new plants and plants about to be reconstructed, $1.50.

For inspecting plans for repairs and alterations, $1.50.

For examining a plant after its erection or reconstruction and before its operation and maintenance, $1.50.

The fee paid for the inspection or examination shall include the issuing of a permit or certificate in case such permit or certificate is granted. No fees shall be charged for detached residences.

SEC. 11. The issuance and delivery by the smoke inspector of a permit or certificate for the construction or reconstruction or for the alteration or repair of any plant, fireplace, or chimney connected with the plant shall not be held to exempt any person or corporation to whom any such permit has been issued or delivered or who is in possession of any such permit from prosecution on account of the emission or issuance of dense smoke contrary to the provisions of this ordinance.

SEC. 12. The city shall provide such instruments, books, papers, and equipment as shall be necessary for the proper performance of the duties of the smoke inspector, and he shall have charge of such instruments, books, papers, and equipment, and shall deliver the same to his successor in office.

SEC. 13. The smoke inspector shall cause to be kept in his office a complete record of all plans submitted, and of all permits issued, and of all examinations of plants made, and also all certificates issued. He shall make a report of the work of his department to the city council annually, on or before the 1st day of April, and at other times as often as required by the city council.

SEC. 14. If any smoke inspector acting on behalf of the city under the provisions of this chapter shall take or receive any money or any valuable thing or favor for the purpose of favoring any person or persons, or if any inspector shall recommend the issue of any certificate of inspection without having at the time stated thoroughly examined and tested the furnace, device, or apparatus so certified, he shall be subject to a fine of $100 for each offense, and it shall be the duty of the council to promptly suspend from office any smoke inspector against whom a charge of this kind is made, and upon conviction to promptly remove said inspector from office.

SEC. 15. For the purposes of this ordinance " chart," when used, means Ringelmann's smoke chart, as published and used by the United States Geological Survey.

" Stack " means any chimney, smokestack, or other structure, whether of brick, metal, or other material, intended for the emission of smoke. Smokejacks on locomotive roundhouses shall be deemed stacks and a part of the locomotive beneath them for the time being.

SEC. 16. The emission of dense smoke of a degree of density of No. 3 of the chart or greater for more than 6 minutes in any one hour from any stack, chimney, smokestack, or other structure for the purpose of emitting smoke, except as hereinafter provided, is hereby prohibited: *Provided, however*, That until January 1, 1913, smoke of a degree of darkness or density equal to No. 3 of the chart or greater may be emitted for not more than 8 minutes in any one hour: *Provided further*, That in the case of locomotive engines the emission of dense smoke of a degree of density of No. 3 of the chart or greater for more than 40 seconds in any one period of 5 minutes is prohibited after the 1st of January, 1913, and until the 1st of January, 1913, smoke of the degree of density No. 3 of the chart or greater is prohibited for more than 1 minute in any period of 5 minutes: *Provided, further*, That the stacks of locomotives moving trains of six cars or more may be permitted to emit smoke in any 5-minute period for 20 seconds in excess of that already provided for in this act, and that stacks of locomotives in and about roundhouses may emit smoke of a degree of density of No. 3 of the chart or greater for 60 minutes during the period when the fire is being built or rebuilt after cleaning the boiler. The number of minutes or seconds during which the smoke may be emitted in any period as provided in this section shall be deemed to mean the aggregate number of minutes or seconds, and such minutes or seconds need not be consecutive.

SEC. 17. The council may by resolution divide the city into districts and may except from the provisions of this ordinance chimneys emitting smoke from brick and tile kilns or other plants within districts outside of the central part of the city.

SEC. 18. It shall be the duty of the smoke inspector to enforce the provisions of this ordinance, to investigate all complaints made with reference to any violations thereof. Upon the filing with said inspector of a complaint it shall be his duty to proceed at once, either by himself or his assistants, to take observations of the stacks or chimneys complained of, testing the density of the smoke by the chart hereinbefore referred to, and it shall be his duty to keep a record of all such observations, which observations and records shall be open to public inspection at reasonable times and under reasonable regulations. It shall be the inspector's duty to prosecute all persons violating the provisions of this ordinance regulating the emission of dense smoke, and in all cases where the punishment by fine fails to abate the nuisance he shall cause to be brought in the district court in and for Polk County an action for the abatement thereof. All such prosecutions shall be in the name of the city of Des Moines.

SEC. 19. Temporary permits for the emission of smoke covering periods not exceeding six months from July 1, 1911, may be granted by the council to any person duly applying for the same and satisfying the council that he will make changes or improvements to prevent the emission of smoke in violation of the provisions hereof, but after July 1, 1912, no further permits shall be granted unless the council is satisfied that public convenience requires it, and permits so granted shall be for a period not exceeding six months.

SEC. 20. On and after the passage of this ordinance and until the 10th day of April, 1912, all of the duties herein enjoined upon the smoke inspector shall be performed by the person filling the office of fire marshal.

SEC. 21. Any person or corporation who shall violate any of the provisions of this ordinance, except as herein otherwise provided, shall be fined not less than $10 nor more than $100 for each offense.

SEC. 22. This ordinance being deemed urgent and necessary for the public peace, health, and safety, shall be in full force and effect from and after its passage and publication as provided by law.

Signed September 6, 1911.

JAS. R. HANNA, *Mayor.*

The present ordinance of the city of Milwaukee is presented below:

The common council of the city of Milwaukee do ordain as follows:

SECTION 1. Chapter 21 of the general ordinances of the city of Milwaukee, passed May 28, 1906, is hereby amended to read as follows:

"SECTION 1. There is hereby created a new office for the city of Milwaukee which shall be known as the office of smoke inspector, and the person occupying that office at any and all times shall be known by the title of smoke inspector. Such inspector shall be appointed by the mayor, subject to confirmation by the common council, and shall hold office for the term of four years, provided that the mayor may suspend said inspector for cause, and when so suspended shall cease to exercise the functions of his office until he shall be reinstated. Pending the period of suspension, the duties of the office shall be performed by the deputy smoke inspector oldest in the service. In case of such suspension, the mayor shall at once communicate to the common council the charges against the inspector, and the president of the council shall thereupon appoint a committee of five members of the council to consider and examine the same, giving the inspector an opportuntiy to be heard. Said committee shall report to the council as soon as may be its findings and recommendations. If the charges shall not be sustained by the council the inspector shall be immediately reinstated. If the council shall determine that the charges are sustained they shall at once determine whether the good of the city requires that the suspended inspector shall be removed from office or shall be suspended from office without pay for a fixed period. The council shall communicate their decision to the mayor in writing, who shall thereupon make it public. The present incumbent of the existing office of smoke inspector shall be considered appointed as smoke inspector under this ordinance.

"No person shall be eligible to said office unless he is by trade or profession a steam or mechanical engineer with an active practical experience of at least five years in working at said trade or profession. Before entering upon the duties of his office the inspector shall take the oath of office prescribed by the charter. It shall be the duty of the smoke inspector to see that the provisions of this ordinance and all ordinances supplemental to or amendatory thereof and the laws of the State of Wisconsin relating to the suppression of smoke shall be enforced. He shall keep a full and complete record of all the transactions of his office, which shall at all reasonable times be open to public inspection. He shall be provided with an office in the city hall.

"SEC. 2. The salary of the smoke inspector shall be $2,000 per annum, payable in equal monthly installments at the same time and in the same manner that the salaries of other city officials are paid.

"SEC. 3. The said inspector is authorized to employ one clerk, to be selected from the civil-service list of the city, and the clerk shall attend to such duties as the inspector shall direct. The salary of said clerk shall be seventy-five dollars ($75) per month, to be paid monthly from the city treasury in the same manner that the salaries of other city employees are paid.

"SEC. 4. The smoke inspector is authorized to employ two deputy smoke inspectors, to be selected from the civil-service list of the city, and the deputy smoke inspectors shall attend to such duties as the inspector shall direct. The salary of each deputy inspector shall be one hundred dollars ($100) per month, to be paid monthly from the city treasury in the same manner that the salaries of other city employees are paid. The deputy inspectors may be discharged by the inspector for cause.

"SEC. 5. The smoke inspector shall forward to the comptroller on or before the 1st day of November of each year an estimate of the needs of his office.

"SEC. 6. To emit or cause or permit to be emitted into the open air within the corporate limits of the city of Milwaukee, or within 1 mile therefrom, any dense smoke shall be, and is hereby declared to be, a nuisance, and the same is hereby prohibited: *Provided*, That nothing herein contained shall prohibit the emission of dense smoke not to exceed five minutes in any one hour of the day or night.

"The owner or owners of any boat, stationary or locomotive engine, engine used in dredging or driving piles, portable boiler or furnace or tar kettle, and any officer, manager, or agent of any corporation owning any boat, stationary or locomotive engine, engine used in dredging or driving piles, portable boiler or furnace or tar kettle, and the owner, lessee, or occupant of any building, and any officer, manager, or agent of any corporation or company owning, leasing, or occupying any building from which dense smoke is permitted or allowed to issue or to be emitted within the corporate limits of the city of Milwaukee, or within 1 mile therefrom, shall for every such first offense be punished by a fine of not less than twenty-five dollars ($25) nor more than one hundred dollars ($100), and in default of payment by imprisonment in the house of correction of Milwaukee County for a term not to exceed sixty (60) days; for a second offense by a fine of not less than fifty dollars ($50) nor more than one hundred dollars ($100), and in default of payment by imprisonment for a term not to exceed sixty (60) days; for a third and every subsequent offense by a fine of not less than one hundred dollars ($100) nor more than two hundred dollars ($200), and in default of payment by imprisonment for a term not to exceed six (6) months.

"SEC. 7. The smoke inspector shall have the right to enter in the performance of his duties at all reasonable hours all premises where any dense smoke is emitted or where any such boiler or engine is located.

"SEC. 8. Before any person or persons, firm or member of any firm or corporation, or any officer of any corporation, shall construct or alter any stationary steam plant, boiler, or furnace within the corporate limits of the city of Milwaukee, he or they shall make application at the office of the smoke inspector for a permit for that purpose, and shall furnish a written statement, giving the style and dimensions of such steam plant, boiler, or furnace, together with the height and size of stack or chimney and the method or device to be adopted for the prevention of the emission of dense smoke therefrom; and if the matters mentioned in said application and statement be approved by said inspector, he shall issue a permit for the construction of such steam plant, boiler, or furnace. Any person or persons, firm or member of any firm or corporation, or any officer of any corporation who proceeds in such construction or alteration without said permit shall be deemed guilty of a violation of this ordinance, and shall be subject to such penalties as are provided in section 6 of this chapter.

"SEC. 9. All accidents to stationary steam boilers, furnaces, or smoke-preventing devices shall be reported to the smoke inspector in writing, giving the nature of the accident and the time required to repair the same."

SEC. 10. All ordinances or parts thereof contravening or conflicting with the provisions of this ordinance are hereby repealed.

SEC. 11. This ordinance shall take effect and be in force from and after its passage and publication.

Approved, October 12, 1911.

EMIL SEIDEL, *Mayor.*

The Los Angeles ordinance is presented because it was adopted by a city in which oil is the principal fuel.

The mayor and council of the city of Los Angeles do ordain as follows:

SECTION 1. That for the purpose of regulating the discharge of smoke from flues, chimneys, or smokestacks, or from any other structures or appliances from which smoke is discharged, and for the purpose of determining by a comparison the degree of darkness of smoke so discharged, a color scale for the measurement thereof is hereby adopted, as follows:

A white card not less than 5 by 8 inches in size shall be marked with black lines crossing each other at right angles. Each such line shall be 1 millimeter in width and such lines shall be so placed that white spaces 9 millimeters square shall remain between such lines. When a test is being made such card shall be placed at a distance of not more than 55 feet and not less than 45 feet from the observer and as nearly in line as possible between the eyes of the observer and the smoke concerning which the test is being made.

SEC. 2. It shall be unlawful for any person, firm, or corporation to cause, permit, or allow any smoke of a greater degree of darkness than the card described in section 1 hereof when such card is placed at the said distance from the person observing such smoke, to issue or to be discharged from any flue, chimney, or smokestack, or from any other structure or appliance used for the discharge of smoke, or from which smoke is discharged, or from any works, plant, or factory, for a period longer than or for periods aggregating more than five minutes in any one hour of the day or night.

For the purposes of this section a works, plant, or factory shall be deemed to include all buildings and appliances, and all flues, chimneys, and smokestacks connected therewith, and all structures and appliances from which smoke is discharged, located upon any parcel of land which is held, used, or occupied in one body, whether the same contains one or more lots or tracts of land, if such buildings, structures, and appliances, and such flues, chimneys, and smokestacks are owned or used, or are intended to be used by the same person, firm, or corporation in or about the conduct of any business or occupation.

SEC. 3. It shall be unlawful for any person, firm, or corporation to cause, permit, or allow soot, ashes, or cinders to issue or to be discharged from any flue, chimney, or smokestack, or from any other structure or appliance.

SEC. 4. If any flue, chimney, smokestack, or other structure or appliance shall become so filled with soot as to become a menace to adjacent property, it shall be the duty of the person, firm, or corporation owning or using such flue, chimney, smokestack, or other structure or appliance to cause the same to be thoroughly cleaned, and it shall be unlawful for any such person, firm, or corporation to fail, refuse, or neglect so to do. Each such person, firm, or corporation shall be deemed guilty of a separate offense for every day during which such failure, refusal, or neglect continues and shall be punishable therefor as provided by this ordinance.

SEC. 5. It shall be unlawful for any person, firm, or corporation to erect, construct, or maintain, or to cause or permit to be erected, constructed, or maintained any flue, chimney, or smokestack within 50 feet of any window of any adjacent building unless the top of such flue, chimney, or smokestack shall be higher than every portion of such window: *Provided, however,* That the provisions of this section shall not apply in any case where the owner of such adjacent building shall refuse to grant permission to brace such flue, chimney, or smokestack by means of wires attached to such building.

SEC. 6. All officers and inspectors of the health department of the city of Los Angeles are hereby authorized to enter, during reasonable hours, upon any premises upon which is located any flue, chimney, or smokestack, or any other structure or appliance from which any smoke, soot, ashes, or cinders shall be discharged, for the purpose of making an examination as to the cause of the discharge of such smoke, soot, ashes, or cinders, and for the purpose of ascertaining the kind or character of fuel used, and the manner of using the same, and any other fact or facts showing compliance with or violation of this ordinance. Such officers and inspectors shall at least twice each month make a detailed report to the board of health of each such examination, which report shall show all facts ascertained by such examination.

SEC. 7. That any person, firm, or corporation violating any of the provisions of this ordinance shall be deemed guilty of a misdemeanor, and upon conviction thereof shall be punishable by a fine of not more than two hundred dollars ($200) or by imprisonment in the city jail for a period of not more than one hundred (100) days, or by both such fine and imprisonment.

SEC. 8. That ordinance No. 15597 (new series), entitled "An ordinance regulating the discharge of smoke from flues, chimneys, smokestacks, or other structures or appliances from which smoke is discharged, in the city of Los Angeles," approved October 24, 1907, and ordinance No. 16043 (new series), entitled "An ordinance regulating the discharge of soot, ashes, and cinders from flues, chimneys, smokestacks, or other structures or appliances in the city of Los Angeles," approved February 5, 1908, and all ordinances amendatory thereto or thereof, and all other ordinances in conflict with this ordinance be, and the same are hereby, repealed.

Approved February 23, 1911.

GEO. ALEXANDER, *Mayor.*

The Massachusetts act providing for the abatement of smoke in the city of Boston and vicinity reads as follows:

Be it enacted, etc., as follows:

SECTION 1. In this act, unless the context otherwise requires—

"Board" means the board of gas and electric light commissioners—

"District" means the district to which the provisions of this act shall apply, to wit, that part of Boston harbor lying westerly of a line drawn from the southeastern point of Deer Island to the northeastern point of Long Island and the territory comprised within the cities of Boston, Cambridge, Somerville, Everett, and Chelsea, and the town of Brookline.

"Chart" means Ringelmann's smoke chart, as published and used by the United States Geological Survey.

"Stack" means any chimney, smokestack, or other structure, whether of brick, metal, or other material intended for the emission of smoke. Smokejacks on locomotive roundhouses shall be deemed stacks and a part of the locomotive beneath them for the time being.

For the purposes of this act stacks shall be classified as follows:

Class I includes all fixed or stationary stacks having an inside area at the top not exceeding the area of a circle 5 feet in diameter.

Class II includes all fixed or stationary stacks having an inside area at the top greater than the area of a circle 5 feet in diameter but not exceeding the area of a circle 10 feet in diameter.

Class III includes all fixed or stationary stacks having an inside area at the top greater than the area of a circle 10 feet in diameter.

Class IV includes all stacks of vessels having an inside area at the top not exceeding the area of a circle 4 feet in diameter.

Class V includes all stacks of vessels having an inside area at the top greater than the area of a circle 4 feet in diameter.

Class VI includes all stacks on steam locomotives.

SEC. 2. The emission of smoke of a degree of darkness or density equal to No. 2 of the chart, or greater, for more than 6 minutes in any one hour from stacks of Class I; or of a degree equal to No. 3 of the chart, or greater, for more than 3 minutes in any one hour from stacks of Class II; or of a degree equal to No. 2 of the chart, or greater, for more than 25 minutes in any one hour, but not exceeding during said 25 minutes a degree equal to No. 3 of the chart, or greater, for more than 5 minutes from stacks of Class III; or of a degree equal to No. 3 of the chart, or greater, for more than 3 minutes in any one hour from stacks of Class IV, for more than 5 minutes in any one hour from stacks of Class V, and for more than 20 seconds in any one period of 5 minutes from stacks of Class VI, is hereby prohibited.

Provided, however, That during the calendar year 1910 smoke of a degree of darkness or density equal to No. 3 of the chart, or greater, may be emitted for not more than 6 minutes in any one hour from stacks of Class I; and smoke of a degree equal to No. 4 of the chart, or greater, for not more than 5 minutes in any one hour from stacks of Class II, and for not more than 10 minutes in any one hour from stacks of Class III, and for not more than 9 minutes in any one hour from stacks of Class IV, and for not more than 12 minutes in any one hour from stacks of Class V; and of a degree equal to No. 3 of the chart, or greater, for not more than 40 seconds in any one period of 5 minutes from stacks of Class VI; and during the calendar year 1911 smoke of a degree of darkness or density equal to No. 3 of the chart, or greater, may be emitted for not more than 4 minutes in any one hour from stacks of Class I, and for not more than 10 minutes in any one hour from stacks of

Class II; and of a degree equal to No. 3 of the chart, or greater, for not more than 20 minutes in any one hour, but not exceeding during said 20 minutes a degree equal to No. 4 of the chart, or greater, for more than 5 minutes from stacks of Class III; and of a degree equal to No. 3 of the chart, or greater, for not more than 12 minutes in any one hour from stacks of Class IV, and for not more than 15 minutes in any one hour from stacks of Class V, and for not more than 30 seconds in any one period of 5 minutes from stacks of Class VI; and during the calendar year 1912 smoke of a degree of darkness or density equal to No. 2 of the chart, or greater, may be emitted for not more than 8 minutes in any one hour from stacks of Class I; and of a degree equal to No. 3 of the chart, or greater, for not more than 6 minutes in any one hour from stacks of Class II; and of a degree equal to No. 2 of the chart, or greater, for not more than 30 minutes in any one hour, but not exceeding during said 30 minutes a degree equal to No. 3 of the chart, or greater, for more than 10 minutes from stacks of Class III; and of a degree equal to No. 3 of the chart, or greater, for not more than 7 minutes in any one hour from stacks of Class IV, and for not more than 9 minutes in any one hour from stacks of Class V.

And provided further, That stacks of locomotives, moving trains of 6 cars or more, be permitted to emit smoke in any 5-minute period for 10 seconds in excess of that already provided for in this act, and that stacks of Class VI, in and about roundhouses, may emit smoke for 30 minutes during the period when the fire is being built, or rebuilt after cleaning. The number of minutes or seconds during which smoke may be emitted in any period as provided in this section shall be deemed to mean the aggregate number of minutes or seconds, and such minutes or seconds need not be consecutive.

Table showing the density of smoke, in accordance with the Ringelmann chart, which may be emitted from the various classes of stacks as provided in section 2, and the duration of such emission.

Year.	Class of stack.													
	1		2		3		4		5		6		Locomotives moving trains of 6 cars more.	
	Chart number.	Minutes per hour.	Chart number.	Minutes per hour.	Chart number.	Minutes per hour.	Chart number.	Minutes per hour.	Chart number.	Minutes per hour.	Chart number.	Seconds in 5-minute periods.	Chart number.	Seconds in 5-minute periods.
1910	3	6	4	5	4	10	4	9	4	12	3	40	3	50
1911	3	4	3	10	3 including 4	20 including 5	3	12	3	15	3	30	3	40
1912	2	8	3	6	2 including 3	30 including 10	3	7	3	9	3	20	3	30
1913	2	6	3	3	2 including 3	25 including 5	3	3	3	5	3	20	3	30

SEC. 3. The board shall appoint a smoke inspector who shall not engage in any other business, and such deputy inspectors as it may think proper, who shall be sworn to the faithful performance of their duties and shall hold office during the pleasure of the board. The board may also employ such clerks, stenographers, and other office employees as it may deem necessary, and may expend for necessary office rent, books, stationery, travel, and other expenses incidental to the performance of the duties imposed by this act, such sum as the legislature shall annually appropriate. The compensation of inspectors, deputy inspectors, and all other employees shall be fixed by the board, subject to the approval of the governor and council. All salaries and other expenses provided for by this act shall be paid by the Commonwealth, which shall be reimbursed as hereinafter provided.

SEC. 4. It shall be the duty of the board to enforce the provisions of this act, to investigate all complaints made with reference to any violations thereof, and in its discretion to order any person or corporation complained of to comply with the provisions of this act, and to enforce such orders by legal proceedings. The board shall make an annual report to the general court of its doings with such recommendations as to the legislative action or State policy as it may deem advisable. The board, with the approval of the governor and council, may make such rules and regulations as it deems advisable for its own government, for the government of its employees and assistants, for the observation of smoke by the inspector or his duly authorized agents at reasonable intervals, and for keeping proper records of all observations. Such observations and records shall be open to public inspection at reasonable times and under reasonable regulations.

SEC. 5. It shall be the duty of the smoke inspector, by himself and his assistants, to assist the board in the performance of its duties, in such manner as the board shall direct, to investigate complaints as to violations of this act, to collect evidence in regard to the same and present such evidence to the board for action.

SEC. 6. The board shall have power, after notice and a hearing, to order any person or corporation having control of the operation of the stack, other than an employee, to stop or abate the emission of smoke in violation of this act. Such notice shall be in writing and may be served personally upon such person or corporation, or duly authorized agent by any person authorized by the board to make such service, and in the manner provided by the laws of the Commonwealth for the service of writs returnable to the superior court. Such notice shall be served at least 48 hours before the time fixed for the hearing, and a copy of the order or decree of the board shall in like manner be served upon such person or corporation or duly authorized agent within 24 hours after the same shall be made by the board. In the event of violation, a copy of the observation made in accordance with section 4 shall be mailed within 24 hours to the person or corporation having control of the operation of the stack, and an additional copy shall be delivered upon the premises, as soon as is practicable to the employee having charge of the stack, unless it is otherwise requested in writing by any such person or corporation.

SEC. 7. Any person or corporation violating any order of the board shall be guilty of a misdemeanor and may be punished by a fine of not less than ten nor more than fifty dollars for the first offense and not less than twenty nor more than one hundred dollars for every succeeding offense. No person or corporation shall be deemed guilty in accordance herewith, unless the observations, used as evidence at the trial, shall be made as provided in section 4. The superior court sitting in equity, on petition of the board or any person authorized by the board, shall have jurisdiction to restrain violations of this act during the prosecution of any proceeding at law for the enforcement of any order of the board.

SEC. 8. Temporary permits for the emission of smoke, covering periods not exceeding six months from June 1, 1910, may be granted by the board to any person duly applying for the same and satisfying the board that he will make changes or improvements to prevent the emission of smoke in violation of the provisions hereof. But after December 1, 1910, no further permits shall be granted unless the board is satisfied that public convenience requires it, and permits so granted shall be for a period not exceeding six months.

SEC. 9. The board shall annually estimate the expense of carrying this act into effect for the ensuing year and shall certify the same to the treasurer of the Commonwealth, who shall apportion said expense among the cities and towns comprised in the district in proportion to the amount of their State tax, and the treasurer shall annually notify each city and town of the amount to be paid by it, and the same shall be paid by such city or town into the treasury of the Commonwealth at the time required for the payment of, and as a part of, its State tax.

SEC. 10. All acts and parts of acts inconsistent herewith are hereby repealed, and this act shall take effect on the 1st day of July, 1910.

Approved June 15, 1910.

PUBLICATIONS ON FUEL TESTING.

The following Bureau of Mines publications may be obtained free by applying to the Director Bureau of Mines, Washington, D. C.:

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp., 4 pls.

BULLETIN 5. Washing and coking tests of coal at Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp.

BULLETIN 6. Coals available for the manufacture of illuminating gas, by A. H. White and Perry Barker, compiled and revised by H. M. Wilson. 1911. 77 pp., 4 pls.

BULLETIN 7. Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1911. 58 pp., 1 pl.

BULLETIN 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911. 32 pp.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp.

BULLETIN 13. Résumé of producer-gas investigations, October 1, 1904, to June 30, 1910, by R. H. Fernald and C. D. Smith. 1911. 393 pp., 12 pls.

BULLETIN 14. Briquetting tests of lignite at Pittsburgh, Pa., 1908–9; with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 64 pp., 11 pls.

BULLETIN 16. The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl.

BULLETIN 18. The transmission of heat into steam boilers, by Henry Kreisinger and W. T. Ray. 1912. 380 pp.

BULLETIN 19. Physical and chemical properties of the petroleums of the San Joaquin Valley, Cal., by I. C. Allen and W. A. Jacobs, with a chapter on analyses of natural gas from the southern California oil fields, by G. A. Burrell. 1911. 60 pp., 2 pls.

BULLETIN 21. The significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 64 pp. Reprint of United States Geological Survey Bulletin 367.

BULLETIN 23. Steaming tests of coals and related investigations, September 1, 1904, to December 31, 1908, by L. P. Breckenridge, Henry Kreisinger, and W. T. Ray. 1912. 380 pp., 2 pls.

BULLETIN 24. Binders for coal briquets, by J. E. Mills. 56 pp. Reprint of United States Geological Survey Bulletin 343.

BULLETIN 27. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 44 pp., 3 pls. Reprint of United States Geological Survey Bulletin 366.

BULLETIN 28. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 51 pp. Reprint of United States Geological Survey Bulletin 323.

BULLETIN 29. The effect of oxygen in coal, by David White. 80 pp., 3 pls. Reprint of United States Geological Survey Bulletin 382.

BULLETIN 30. Briquetting tests at the United States fuel-testing plant at Norfolk, Va., 1907–8, by C. L. Wright. 41 pp., 9 pls. Reprint of United States Geological Survey Bulletin 385.

BULLETIN 31. Incidental problems in gas-producer tests, by R. H. Fernald, C. D. Smith, J. K. Clement, and H. A. Grine. 29 pp. Reprint of United States Geological Survey Bulletin 393.

BULLETIN 32. Commercial deductions from comparisons of gasoline and alcohol tests on internal-combustion engines, by R. M. Strong. 38 pp. Reprint of United States Geological Survey Bulletin 392.

BULLETIN 33. Comparative tests of run-of-mine and briquetted coal on the torpedo boat *Biddle*, by W. T. Ray and Henry Kreisinger. 50 pp. Reprint of United States Geological Survey Bulletin 403.

BULLETIN 34. Tests of run-of-mine and briquetted coal in a locomotive boiler, by W. T. Ray and Henry Kreisinger. 33 pp. Reprint of United States Geological Survey Bulletin 412.

BULLETIN 35. The utilization of fuel in locomotive practice, by W. F. M. Goss. 29 pp. Reprint of United States Geological Survey Bulletin 402.

BULLETIN 36. Alaskan coal problems, by W. L. Fisher. 1911. 32 pp., 1 pl.

BULLETIN 37. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests, and some foreign specifications for briquetted fuel, by W. F. M. Goss. 58 pp., 4 pls. Reprint of United States Geological Survey Bulletin 363.

BULLETIN 39. The smoke problem at boiler plants, a preliminary report, by D. T. Randall. 188 pp. Reprint of United States Geological Survey Bulletin 334, revised by S. B. Flagg.

BULLETIN 40. The smokeless combustion of coal in boiler furnaces, with a chapter on central heating plants, by D. T. Randall and H. W. Weeks. 188 pp.

Reprint of United States Geological Survey Bulletin 373, revised by Henry Kreisinger.

BULLETIN 41. Government coal purchases under specifications, with analyses for the fiscal year 1909–10, by G. S. Pope, with a chapter on the fuel-inspection laboratory of the Bureau of Mines, by J. D. Davis. 1912. 97 pp., 3 pls.

BULLETIN 43. Comparative fuel values of gasoline and denatured alcohol in internal-combustion engines, by R. M. Strong and Lauson Stone. 1912. 243 pp., 3 pls.

TECHNICAL PAPER 1. The sampling of coal in the mine, by J. A. Holmes. 1911. 18 pp.

TECHNICAL PAPER 2. The escape of gas from coal, by H. C. Porter and F. K. Ovitz. 1911. 14 pp.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

TECHNICAL PAPER 5. The constituents of coal soluble in phenol, by J. C. W. Frazer and E. J. Hoffman. 1912. 20 pp.

TECHNICAL PAPER 8. Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1912. 21 pp.

TECHNICAL PAPER 9. The status of the gas producer and of the internal-combustion engine in the utilization of fuels, by R. H. Fernald. 1912. 42 pp.

TECHNICAL PAPER 10. Liquefied products from natural gas; their properties and uses, by I. C. Allen and G. A. Burrell. 1912. 23 pp.

TECHNICAL PAPER 16. Deterioration and spontaneous combustion of coal in storage, preliminary report, by H. C. Porter and F. K. Ovitz. 1912. 14 pp.

TECHNICAL PAPER 20. The slagging type of gas producer with a brief report of preliminary tests, by C. D. Smith. 1912. 14 pp.

TECHNICAL PAPER 25. Methods for the determination of water in petroleum and its products, by I. C. Allen and W. A. Jacobs. 1912. 13 pp.

TECHNICAL PAPER 26. Methods of determining the sulphur content of fuels, especially petroleum products, by I. C. Allen and I. W. Robertson. 1912. 13 pp.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

The following Bureau of Mines publications are no longer available for free distribution, but may be obtained by purchase from the Superintendent of Documents, Government Printing Office, Washington, D. C. Prepayment of the price is required and should be made in cash (exact amount) or by postal or express money order payable to the Superintendent of Documents.

BULLETINS.

9. Recent development of the producer-gas power plant in the United States, by R. H. Fernald. 82 pp., 2 pls. Reprint of United States Geological Survey Bulletin 416. 15 cents.

11. The purchase of coal by the Government under specifications, by G. S. Pope. Reprint of United States Geological Survey Bulletin 428. 10 cents.

Bulletin 50

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, Director

A LABORATORY STUDY
OF THE
INFLAMMABILITY OF COAL DUST

BY

J. C. W. FRAZER, E. J. HOFFMAN
AND
L. A. SCHOLL, Jr.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

First edition, June, 1913.

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A LABORATORY STUDY OF THE INFLAMMABILITY OF COAL DUST.

By J. C. W. Frazer, E. J. Hoffman, and L. A. Scholl, Jr.

INTRODUCTION.

The danger from coal dust in mines has been thoroughly demonstrated by experiment, and consequently the study of the inflammability of coal dust suspended in air, that is, the readiness with which a cloud of coal dust inflames, is of decided importance to those engaged in coal mining. Much knowledge has been gained from the work done in the large galleries constructed at official and semiofficial stations in this country and abroad, but the study of the coal-dust problem in these galleries requires so much time and is so costly that there is need of a reliable laboratory method for obtaining a classification of the great variety of dusts that occur in mines. The investigation described in this paper was an attempt to devise such a method. It was a preliminary investigation, and work in the same direction is being continued by the Bureau of Mines. As Mr. Frazer has severed his connection with the bureau, it is deemed advisable to publish the results of his study substantially as he prepared them, with little attempt to draw conclusions or to show the bearing of the results on other studies now in progress. The results of these studies and a full discussion of the significance of the laboratory investigations will be published in future reports of the Bureau of Mines.

The reader should remember that any laboratory method, since it involves conditions that differ so greatly from those of actual mining, should be thoroughly tested, and the results obtained by it should be confirmed by experiments conducted on a scale simulating mining conditions before final conclusions are drawn.

The need of a laboratory method has long been felt, and several investigators have devised apparatus and methods. The work done by Vital, Holtzwart and Von Meyer, Bedson and Widdas, Le Chatelier, and that of the British Coal Dust Commission is of great interest in this connection. Bureau of Mines Bulletin 20[a] contains a summary of the experiments of some of those who have made a laboratory study of the inflammability of coal dust and it is unnecessary to repeat the summary here. More recently, Taffanel and Durr have published the results of their investigation of the inflammability of dusts at the Liévin station.

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[a] Rice, G. S., The explosibility of coal dust, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz: Bull. 20, Bureau of Mines, 1911, 204 pp.

WORK AT THE LIÉVIN STATION.

The paper of Taffanel and Durr [a] gives some interesting results of the comparative study of combustible dusts. The apparatus which they used is shown in figure 1. A vertical porcelain tube, *a*, is heated from the outside to the desired temperature, as indicated by the thermocouple *d*. The dust under investigation is placed at *o* and is ejected by the compressed air contained in the 1-liter bottle *p*. Just previous to the ejection of the dust by the current of air, *e* is pressed down tightly on *a*, *f* making a tight joint between the two. During the passage of the dust-laden air through *a*, ignition occurs if *a* is sufficiently hot. In addition to determining the temperature of ignition, the investigator should study the size of the flame that issues from the lower end of *a*. This study is facilitated by photographing the flames. The results recorded permit the classification of the dusts with reference to their inflammability. The dusts studied by Taffanel and Durr were classified into eight groups, designated A to H in the order of increasing inflammability.

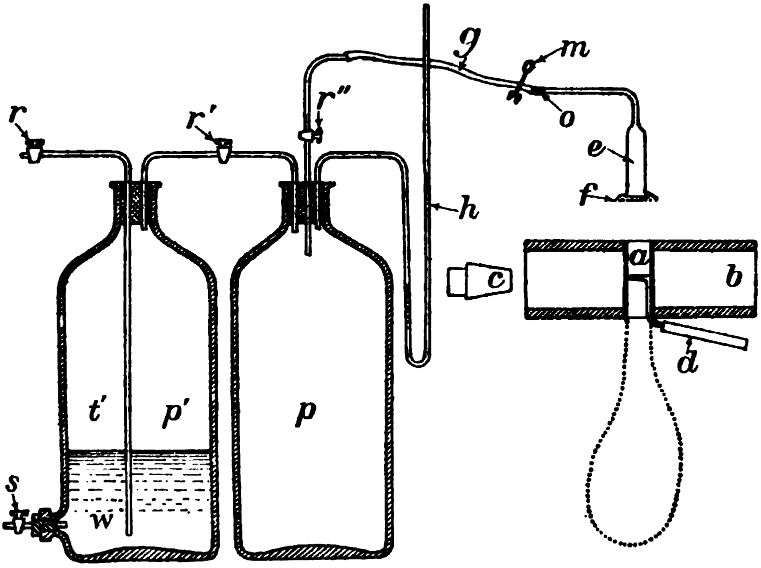

FIGURE 1.—Apparatus used at the Liévin station.

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[a] Taffanel, J., and Durr, —, Cinquième série d'essais. Sur les inflammations de poussières; Essais d'inflammabilité. August, 1911.

WORK BY THE BUREAU OF MINES.

DESCRIPTION OF APPARATUS.

The apparatus that was used by the authors in the present investigations is shown in figure 2. It consists essentially of the explosion flask *a*, the platinum coil *i*, and devices for putting the dust in suspension and for measuring the pressure developed in *a*.

The flask *a*, which has a capacity of 1,600 c. c., is provided with large tubulures at its top and bottom; the ends of these tubulures are ground true on a glass plate with emery powder. Experience indicates that a flask with a capacity of about 1,250 c. c. would probably be preferable. The brass plate *k*, which rests on the end of the top tubulure, carries the platinum coil *i* and the brass tube *m*. The brass plate *c*, on which *a* rests, carries the small glass funnel *b*, which is cemented gas-tight into *c*. The contact between the ends of *a* and the brass plates *k* and *c* is made gas-tight by wide rubber bands, which are placed around the end of each tubulure and left projecting a short distance. The contraction of the rubber draws the projecting portion down on the ends, forming a rubber cushion between the ends of the tubulures and the brass plates, and by screwing down the nuts above the steel piece *l*, the joints at these points are made tight. The platinum coil *i* is suspended near the center of *a* by the two stout nickel leads *j*, *j*, which pass through fiber

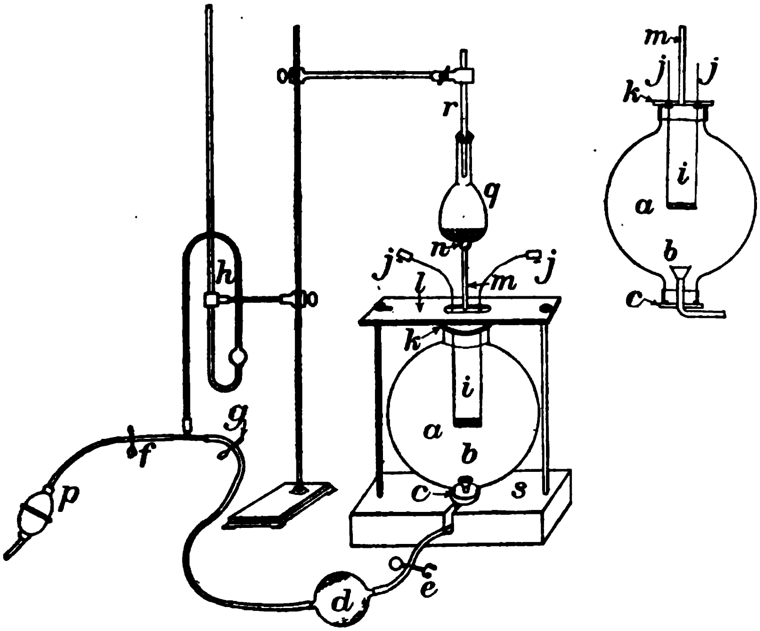

FIGURE 2.—Apparatus used by the Bureau of Mines.

plugs in *k*. The coil *i* is made of about 100 cm. of No. 26 platinum wire, wound on a quartz-glass frame, which is attached as described above to the leads *j*, *j*. The steel ball *n* is ground to fit practically gas tight on top of *m*, which is soldered to *k* and communicates with *a*.

The dust to be investigated is weighed into the glass funnel *b* and at each trial is brought to about the same position in the stem of the funnel, which is then connected by means of a short rubber tube to the 150-c. c. glass bulb *d*. By means of the compression bulb, *p*, the air in *d* is compressed until a pressure of 150 mm. of mercury is indicated by the manometer *h*. At the proper instant the dust in *b* is ejected and put in suspension in *a* by suddenly opening the pinch cock *e*. In order to insure a more uniform dissemination of the dust in *a*, *b* is covered with a small piece of 18-mesh copper gauze. By blowing the dust through the gauze the adhering particles are more completely separated and the density of the dust cloud in *a* is rendered more uniform. It has been found inadvisable to use the gauze on *b*, except with samples of coal dust. The pressure developed in *a* is determined by ascertaining by several trials the smallest weight that must be placed on *n* to prevent its being lifted from *m*.

METHOD OF OPERATION.

With the apparatus connected as shown in the illustration (fig. 2), the desired current is passed through the platinum coil for exactly 3 minutes, and during this interval the expanding air in *a* is released at intervals of 1, 2, and 2¾ minutes after the instant the current is first passed through the coil. At the end of exactly 3 minutes *e* is quickly opened and the dust in *b* is ejected. The experiment is repeated several times, the weight on *n* being varied each time until it is found that the pressure developed in *a* lies between two values differing by 5 grams. The weight, which is a small flask or other glass vessel containing mercury, is easily varied. In every experiment 0.05 gram of dust was used for ignition, as with this quantity it has been found that the most inflammable coals are still able to exert the maximum explosive force.

In order to obtain comparable results, the conditions must be kept uniform in every particular. A 220-volt power-house current was used in these experiments, its voltage being reduced by suitable resistance before it passed to the coil *i*. An ammeter was always in circuit, and the current was kept as steady as possible by means of a rheostat, but frequently the current was so unsteady that some tests had to be repeated several times before the results were satisfactory. This was especially true when conditions within the flask were just about those required for the complete ignition of the dust. Hence, a storage battery should be used as the source of the current.

Experiments were made on each dust with current strengths of 5, 5.5, 6, 6.5, and 7 amperes. The temperature corresponding to each of these intervals could not be readily determined, but the resistance of the coil at each interval was determined, as follows:

Resistance of coil with different strengths of current.

Amperes	5.0	5.5	6.0	6.5	7.0
Ohms	3.6	3.74	3.85	3.90	3.97

PREPARATION OF THE SAMPLE.

Previous experiments had shown that when the particles are below a certain size the fineness of the particles has a decided effect on the inflammability of a dust. But it was considered better to grind all of the samples so fine that the whole of each sample introduced would take part in the action within the flask than to attempt to separate and collect the finest dust by screening, as the finest dust might have a composition different from that of the sample as a whole. In all of the tests recorded in this paper the whole of each sample was air dried to constant weight and then ground fine enough to pass through a 200-mesh sieve, the fineness of all the samples being as nearly as possible the same. Some samples undoubtedly contained more extremely fine dust than did others, but it is not believed that this finest part and that which just passes a 200-mesh screen would differ much in inflammability under the conditions of these experiments.

ACKNOWLEDGMENTS.

The samples were collected under the supervision of G. S. Rice, chief mining engineer, who took much interest in the investigation and was consulted frequently by the authors during its progress.

The samples were analyzed under the direction of A. C. Fieldner, chemist. The methods used were those adopted by the Bureau of Mines.[a] The authors are much indebted to Mr. Fieldner and his assistants for the preparation and analysis of the samples.

STATEMENT OF RESULTS.

In the following tables are given the results of the investigation. All of the experiments were made under the same conditions, except those with artificial mixtures (Table 4 and figs. 71–75), in which an explosion flask of a different size was used. Except for those tests, all results are comparable. In every case the pressure from the air used to put the dust into suspension has been deducted from the pressure caused by the explosion.

In addition to samples of coal dust, some artificial mixtures of coal dust and finely ground shale, also calcium carbonate, have been investigated in order to measure the effectiveness of these substances in diminishing the inflammability of coal dust. The following substances also were investigated: Wood dusts (4 samples),, asphalt (4 samples), and gluten, flour, starch, sugar, and lycopodium (1 sample of each).

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[a] Stanton, F. M., and Fieldner, A. C., Methods of analyzing coal and coke: Technical Paper 8, Bureau of Mines, 1912, 18 pp.

In order to present the results in a form more convenient than tables, they, with the exception of those for road dusts (Table 3), are shown as curves. The curves are plotted with the strength of current on the coil as abscissas, and the pressures in the flask as ordinates; the maximum weight in grams lifted in a test is taken as the pressure corresponding to the strength of current in that test. Since the diameter of the brass tube *m* (fig. 2) is 7 mm., the pressure per unit area can be calculated if desired. The heights of any two curves at corresponding points are assumed to be determined by the relative inflammability of the two dusts under the conditions corresponding to the points. The curves of any group of tests are arranged in ascending order according to the increasing inflammability of the samples, as shown by the heights of the curves above the line of zero pressure at the highest current strength used in the coil. Several samples, as the curves show, have about the same inflammability. In such cases the order in which the results are placed is largely a matter of opinion.

The dusts investigated have been divided into four groups, according to their nature as follows: Group 1 (Tables 1 and 2 and figs. 3–70), samples of coal dust; group 2 (Table 3), samples of road dusts high in ash; group 3 (Table 4 and figs. 71–75), artificial mixtures of dusts with known percentages of shale dust or of calcium carbonate; group 4 (Table 5 and figs. 76–86), inflammable dusts other than coal dusts.

It will be noticed that, in general, the curves are of two types and the dusts of group 1 have been subdivided into two divisions corresponding to the two types of curves. The curves for the samples of the first division rise continuously in a more or less irregular manner with increasing temperature of the coil, whereas those for the second division rise rapidly at first but toward the end of the range covered by these experiments rise little and are practically parallel to the horizontal axis. These results seem to indicate that the samples of the second division of group 1 exerted their maximum explosive force within the range of the tests, whereas those of the first division did not. It seems that many of the samples of the first division did not ignite or that the ignition extended only a short distance into the cloud of dust. In none of the samples of the first division does the ignition seem to have extended throughout the whole cloud, for the curves of this division ascend continuously throughout their whole length, and the maximum explosive force of the samples was not developed within the range of the experiments.

TABLE 1.—*Dusts of group 1A, coals and lignites.*

Laboratory number and description.	Chemical analysis (air-dried sample).							Inflammability.[a]	Weight lifted at different current strengths.					For curve see fig. No. —
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Oxygen.	Nitrogen.		5.0 amp.	5.5 amp.	6.0 amp.	6.5 amp.	7.0 amp.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
10900. Montana, Valley County, 7 miles NW. of Mondak; outcrop; lignite.	12.49	40.65	40.75	6.11	0.56	33.45	1.15	1	....	....	5	13	25	3
11680. West Virginia; McDowell County; Berwind; Berwind mine; Pocahontas bed; semibituminous coal.	.53	16.22	71.39	11.86	2.16	....	....	2	....	5	8	18	38	4
11360. Pennsylvania; Cambria County; Portage Station; Miller shaft No. 1; Miller bed; semibituminous coal.	.68	18.03	74.86	6.43	1.25	3.16	1.26	3	....	5	15	23	53	5
11361. Montana, Dawson County, 9 miles NW. of Glendive; Dick mine; A bed; lignite.	17.78	31.51	44.21	6.50	.47	....	....	4	....	8	13	33	63	6
10630. West Virginia, Raleigh County; Raleigh; mine No. 2; Bechley bed; semibituminous coal.	.51	18.41	77.40	3.68	.64	3.49	1.60	5	....	8	13	38	63	7
10629. West Virginia, Fayette County; Thayer; Slater-Buffalo mine; Fire Creek bed; semibituminous coal.	.69	18.93	72.68	7.70	1.10	3.82	1.60	6	....	8	18	48	85	8
10628. West Virginia, Raleigh County; Raleigh; mine No. 3; Bechley bed; semibituminous coal.	.59	18.77	77.01	3.63	.74	3.38	1.55	7	....	8	18	38	103	9
10623. West Virginia, Fayette County; South Nuttal; Brown mine; Sewell bed; semibituminous coal.	.83	25.45	70.91	2.81	.60	4.62	1.61	8	....	13	18	33	133	10
10732. Colorado, El Paso County; Calhan; Mosby mine; Mosby bed; subbituminous coal.	15.57	32.77	34.12	17.54	.38	28.92	.86	9	16	28	68	93	133	11
11135. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	1.00	28.90	55.78	14.32	.63	6.91	1.16	10	....	13	28	113	133	12
11134. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	1.28	29.39	56.00	13.33	.57	8.00	1.16	11	....	13	18	123	143	13
11107. Colorado, Delta County; Dominguez; Wells Gulch mine; —— bed; bituminous coal.	2.57	31.41	48.59	17.43	1.90	....	....	12	....	8	13	138	143	14

[a] The relative inflammability of the dusts is based on the results of the tests in which the greatest current strength was on the wire (see p. 8), and the dust least inflammable with that current strength under the conditions of the tests is ranked 1 in this table.

TABLE 1.—*Dusts of group 1A, coals and lignites*—Continued.

Laboratory number and description.	Chemical analysis (air-dried sample).							Inflammability.	Weight lifted at different current strengths.					For curve see fig. No.—
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Oxygen.	Nitrogen.		5.0 amp.	5.5 amp.	6.0 amp.	6.5 amp.	7.0 amp.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
10692. Tennessee, Rhea County; Dayton; North Pole-Richland mine; Richland bed; bituminous coal.	1.07	29.05	57.98	11.90	1.80	5.13	1.27	13	....	18	38	153	153	15
12198. Colorado, Las Animas County; Starkville; Starkville mine; Starkville bed; bituminous coal.	1.22	29.23	52.77	16.78	.56	6.81	1.11	14	8	18	28	145	163	16
11059. Wyoming, Johnson County, 50 miles north of Casper; open bank; subbituminous coal.	13.63	32.61	38.19	15.57	1.60	25.66	1.04	15	8	43	93	138	168	17
12086. Alabama, Jefferson County; Littleton; Banner mine; Big or Mary Lee bed; bituminous coal.	1.15	27.32	60.32	11.21	.80	6.17	1.61	16	....	15	23	128	170	18
11443. Colorado, Las Animas County; Delagua; Delagua mine; Delagua bed; bituminous coal.	1.24	35.08	53.14	10.54	.56	9.42	1.41	17	....	25	48	135	175	19
10801. Tennessee, Bledsoe County; Litton; Thurman mine; Richland bed; bituminous coal.	1.06	27.29	64.21	7.44	.53	....	....	18	....	13	20	143	178	20
11163. Pennsylvania, Washington County, Monongahela City; Catsburg mine; Pittsburgh bed; bituminous coal.	1.05	34.12	58.34	6.49	1.13	7.18	1.35	19	....	18	28	153	178	21
11170. Pennsylvania, Washington County; Band Station; Schoenberger mine; Pittsburgh bed; bituminous coal.	1.07	34.55	58.51	5.87	1.07	6.97	1.41	20	....	18	33	158	183	22
11156. West Virginia, Marion County; Worthington; Hutchinson mine; Pittsburgh bed; bituminous coal.	1.22	36.39	53.58	8.81	2.06	6.98	1.27	21	....	23	48	160	188	23
12029. Colorado, Las Animas County; Hastings; Hastings mine; Hastings bed; bituminous coal.	.83	32.77	49.09	17.31	.94	8.10	1.22	22	....	23	40	178	190	24
10741. Colorado, El Paso County, 3 miles SW. of Ramah; Purdon mine; Purdon bed; subbituminous coal.	11.31	31.36	32.98	24.35	.43	25.41	.72	23	....	18	78	153	193	25
10713. Utah, Uinta County, 8 miles east of Vernal; Eph Green mine; bituminous coal.	7.75	39.27	44.65	8.33	2.39	....	....	24	....	48	98	188	193	26

11433. West Virginia, Marion County; Monongah; mine No. 63. Pittsburgh bed; bituminous coal.	1.47	35.54	57.30	5.69	.68	7.91	1.40	26	....	23	55	153	198	27
10916. Tennessee, Bledsoe County; Pikeville; No. 3 mine; Sewanee bed (?); bituminous coal.	1.68	29.92	61.91	6.49	.53	....	....	26	....	18	43	163	198	28
10959. Illinois, Madison County; Collinsville; No. 3 mine; No. 6 bed; bituminous coal.	7.52	38.52	43.93	10.03	3.89	15.01	1.05	27	....	38	63	168	198	29
11006. Montana, Valley County, 6 miles NE. of Medicine Lake; Jones mine; Jones bed; lignite.	9.36	41.40	40.59	8.65	.62	33.30	1.03	28	8	43	83	188	198	30
11382. Alaska, Matanuska field; outcrop; bituminous coal..	4.76	36.00	53.85	5.39	.24	18.74	1.20	29	....	25	58	153	203	31
10997. Utah, Wasatch County, 2 miles east of Hanna; Winchester prospect; Mancos bed; subbituminous coal.	10.37	39.68	46.75	3.20	.74	....	....	30	8	38	58	163	203	32
11592. Oklahoma, Pittsburg County, 2 miles north of Alderson; Alderson No. 38 mine; McAlester bed; bituminous coal.	1.52	33.28	58.04	7.16	.50	8.67	1.65	31	....	15	28	183	203	33
12025. Colorado, Las Animas County; Primero; Primero mine; Primero bed; bituminous coal.	.77	31.58	57.57	10.08	.60	6.93	1.68	32	13	33	43	128	208	34
10575. Washington, Pierce County; Carbonado; Carbonado mine No. 4; Carbonado bed No. 4; bituminous coal.	1.68	35.24	48.02	15.06	.35	8.18	1.94	33	8	43	83	178	208	35
11465. Wyoming, Sweetwater County; Thayer Junction; B mine; No. 7 bed; bituminous coal.	4.64	39.96	51.76	3.64	1.07	14.88	1.56	34	....	23	68	168	213	36
10556. Pennsylvania, Allegheny County; Oak Station; Oak mine; Pittsburgh bed; bituminous coal.	1.90	35.59	57.87	4.64	.52	9.19	1.53	35	8	33	73	173	213	37
10961. Indiana, Sullivan County; Dugger; No. 10 mine; No. 4 bed; bituminous coal.	7.37	34.81	51.79	6.03	1.17	14.95	1.60	36	....	43	73	188	213	38
11354. Illinois, Montgomery County; Panama; Panama mine; No. 6 bed; bituminous coal.	6.48	36.27	44.60	12.65	4.05	13.83	1.02	37	....	33	83	188	213	39
11184. Kansas, Crawford County; Fuller; No. 2 shaft; bituminous coal.	1.50	34.71	54.37	9.42	5.12	5.60	1.28	38	....	13	73	155	218	40
11130. Pennsylvania, Allegheny County; Creighton; Hite mine; Freeport bed; bituminous coal.	1.51	35.22	56.67	6.60	.97	....	....	39	....	43	73	168	218	41
11180. Missouri, Barton County, 1 mile NE. of Minden; Pullen No. 1 mine; bituminous coal.	1.28	33.47	55.91	9.34	3.78	5.60	1.43	40	....	23	48	203	218	42
11188. Missouri, Barton County, 2 miles NW. of Minden; No. 17 shaft; bituminous coal.	1.64	32.37	53.99	12.00	5.22	6.16	1.14	41	....	8	53	178	220	43

TABLE 1.—*Dusts of group 1A, coals and lignites*—Continued.

Laboratory number and description.	Chemical analysis (air-dried sample).							Inflammability.	Weight lifted at different current strengths.					For curve see fig. No.—
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Oxygen.	Nitrogen.		5.0 amp.	5.5 amp.	6.0 amp.	6.5 amp.	7.0 amp.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
12028. Colorado, Las Animas County; Hastings; Hastings mine; Hastings bed A; bituminous coal.	1.27	33.18	56.16	9.39	0.63	7.95	1.37	42	....	43	100	138	223	44
10960. Indiana, Sullivan County; Dugger; No. 10 mine; No. 4 bed; bituminous coal.	7.20	36.61	50.81	5.38	.88	14.60	1.54	43	....	48	83	185	223	45
12004. Kentucky, Pike County; Hellier; Edgewater mine; Upper Elkhorn bed; car sample; bituminous coal.	1.45	35.66	60.18	2.71	.57	8.16	1.43	44	....	43	88	208	223	46
11984. Pennsylvania, Allegheny County; Bruceton; experimental mine; Pittsburgh bed; bituminous coal.	1.70	35.73	56.32	6.25	1.49	....	....	45	....	48	98	213	223	47
10739. Virginia, Russell County, 2 miles north of Dante; No. 5 mine; Upper Banner bed; bituminous coal.	.78	36.37	57.45	5.40	.58	5.89	1.45	46	....	58	93	198	228	48
10736. Virginia, Russell County, 2 miles north of Dante; No. 2 mine; Upper Banner bed; bituminous coal.	.98	35.60	57.54	5.88	.60	5.25	1.46	47	....	53	95	203	228	49
10845. Pennsylvania, Allegheny County; Oak Station; Pittsburgh bed; bituminous coal.	1.81	35.76	56.41	6.02	1.20	8.95	1.47	48	8	58	98	198	230	50
11569. Oklahoma, Pittsburg County, 2 miles east of McAlester; Bushley No. 5 mine; McAlester bed; bituminous coal.	1.41	34.44	58.87	5.28	.55	7.89	1.72	49	....	8	55	163	233	51
11460. Wyoming, Sweetwater County; Thayer Junction; No. 6 mine; No. 1 bed; bituminous coal.	3.88	39.55	52.81	3.76	1.11	15.24	1.38	50	....	38	98	203	233	52
11965. Pennsylvania, Allegheny County; Bruceton; experimental mine; Pittsburgh bed; bituminous coal.	1.67	35.85	55.73	6.75	1.51	....	....	51	....	58	98	218	233	53
11983. Pennsylvania, Allegheny County; Bruceton; Experimental mine; Pittsburgh bed; bituminous coal.	1.83	35.62	56.69	5.86	1.19	....	....	52	....	53	103	220	233	54
11919. Oklahoma, Pittsburg County; 1.5 miles SW. of Alderson; Alderson No. 5 mine; McAlester bed; bituminous coal.	1.89	35.69	58.00	4.42	.63	8.59	1.72	53	....	23	83	203	243	55

11594. Oklahoma, Pittsburg County; 2 miles east of Alderson; Alderson No. 38 mine; McAlester bed; bituminous coal.	1.60	34.06	59.24	5.10	.50	8.54	1.60	54	....	13	68	208	243	56
11058. Utah, Wasatch County; 28 miles SE. of Neber; E. J. Cummins mine (abandoned); subbituminous coal.	14.35	39.24	39.83	6.58	.73	....	....	55	....	13	113	233	243	57
11930. Colorado, Las Animas County; Forbes; Forbes No. 9 mine; Walsen bed; bituminous coal.	.86	31.07	57.39	10.68	.62	6.14	1.33	56	13	23	68	208	248	58
10189. Colorado, Huerfano county; 9 miles from Walsenberg; Pinon mine; Cameron bed; bituminous coal.	4.83	37.81	49.61	7.75	.57	....	....	57	43	88	148	228	248	59
10909. Utah, Carbon County; Hiawatha; Hiawatha No. 2 mine; Hiawatha bed (?); bituminous coal.	3.33	41.79	47.76	7.12	.57	13.89	1.42	58	23	108	133	263	263	60

TABLE 2.—*Dusts of group 1B, chiefly subbituminous coals.*

Laboratory number and description.	Chemical analysis (air-dried sample).							Inflammability.[a]	Weight lifted at different current strengths.					For curve see fig. No.—
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Oxygen.	Nitrogen.		5.0 amp.	5.5 amp.	6.0 amp.	6.5 amp.	7.0 amp.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
10671. Wyoming, Natrona County, 25 miles SW. of Casper; White Ash mine; subbituminous coal.	12.21	34.22	46.89	6.68	0.59	....	....	1	18	68	138	173	188	61
10899. Montana, Valley County, 15 miles east of Medicine Lake; Belgon mine; lignite.	11.18	38.82	42.70	7.30	.54	29.85	0.99	2	13	58	163	220	228	62
10998. Utah, Wasatch County, 12 to 15 miles SW. of Hanna; subbituminous coal.	6.14	42.29	45.04	6.53	.90	....	....	3	53	103	183	233	253	63
10810. Wyoming, Sheridan County; Acme; Acme No. 2 mine, "Carney vein"; subbituminous coal.	15.17	35.31	45.82	3.70	.40	29.32	1.09	4	....	138	188	228	258	64
10827. Wyoming, Johnson County, 65 miles north of Casper; subbituminous coal.	15.52	39.34	39.43	5.71	.64	30.37	.77	5	48	143	203	243	258	65
10825. Wyoming, Sheridan County; Acme; Acme No. 1 mine, "Carney vein;" subbituminous coal.	13.49	36.33	45.10	5.08	.34	27.93	1.22	6	43	133	203	238	263	66
11048. Wyoming, Converse County, 20 miles north of Glenrock; open bank; subbituminous coal.	16.08	36.91	41.62	5.39	.53	31.10	.81	7	73	143	188	253	278	67
10822. Wyoming, Sheridan County; Kool; Kool mine; Monarch bed; subbituminous coal.	13.94	35.12	45.44	5.50	.56	28.36	1.08	8	....	138	213	243	278	68
12006. Wyoming, Sheridan County; Monarch; Monarch mine; Monarch bed; subbituminous coal.	14.90	37.28	43.82	4.00	.43	28.11	1.14	9	58	125	208	243	288	69
12008. Wyoming, Sheridan County; Monarch; Monarch mine; Monarch bed; subbituminous coal.	14.97	35.24	46.22	3.57	.41	28.47	1.21	10	....	138	208	253	308	70

[a] The relative inflammability of the dusts is based on the results of the tests in which the greatest current strength was on the wire (see p. 8), and the dust least inflammable with that current strength under the conditions of the tests is ranked 1 in this table.

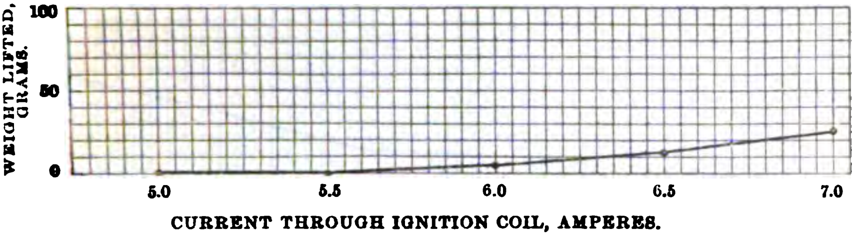

FIGURE 3.—Relative inflammability of coal No. 10900, Valley County, Mont. Moisture, 12.49 per cent; volatile matter, 40.65 per cent; fixed carbon, 40.75 per cent; ash, 6.11 per cent; sulphur, 0.56 per cent.

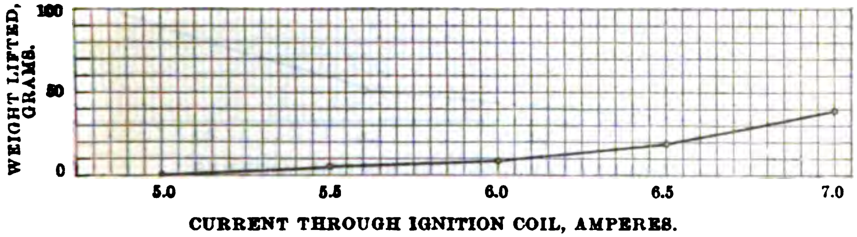

FIGURE 4.—Relative inflammability of coal No. 11680, McDowell County, W. Va. Moisture, 0.53 per cent; volatile matter, 16.22 per cent; fixed carbon, 71.39 per cent; ash, 11.86 per cent; sulphur, 2.16 per cent.

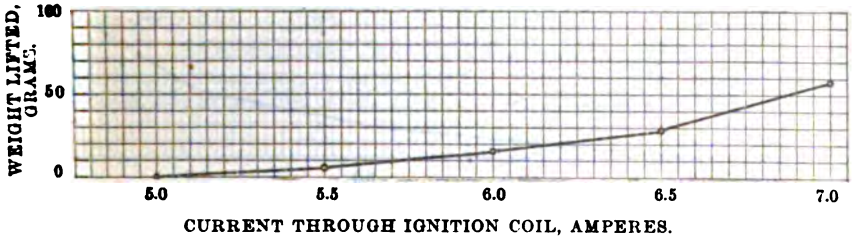

FIGURE 5.—Relative inflammability of coal No. 11360, Cambria County, Pa. Moisture, 0.68 per cent; volatile matter, 18.03 per cent; fixed carbon, 74.86 per cent; ash, 6.43 per cent; sulphur, 1.25 per cent.

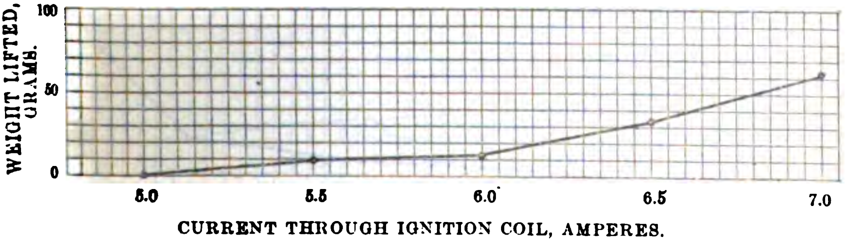

FIGURE 6.—Relative inflammability of coal No. 11361, Dawson County, Mont. Moisture, 17.78 per cent; volatile matter, 31.51 per cent; fixed carbon, 44.21 per cent; ash, 6.50 per cent; sulphur, 0.47 per cent.

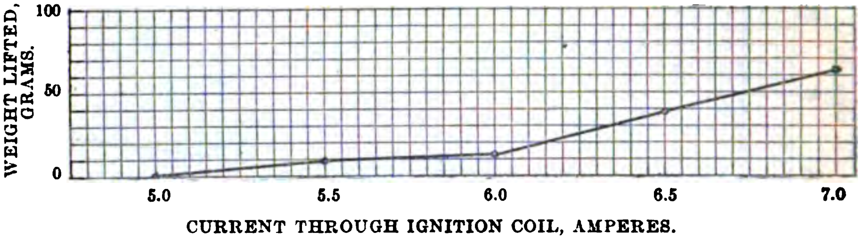

FIGURE 7.—Relative inflammability of coal No. 10630, Raleigh County, W. Va. Moisture, 0.51 per cent; volatile matter, 18.41 per cent; fixed carbon, 77.40 per cent; ash, 3.68 per cent; sulphur, 0.64 per cent.

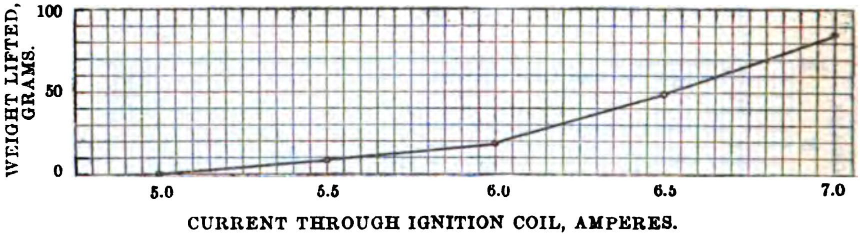

FIGURE 8.—Relative inflammability of coal No. 10629, Fayette County, W. Va. Moisture, 0.69 per cent; volatile matter, 18.93 per cent; fixed carbon, 72.68 per cent; ash, 7.70 per cent; sulphur, 1.10 per cent.

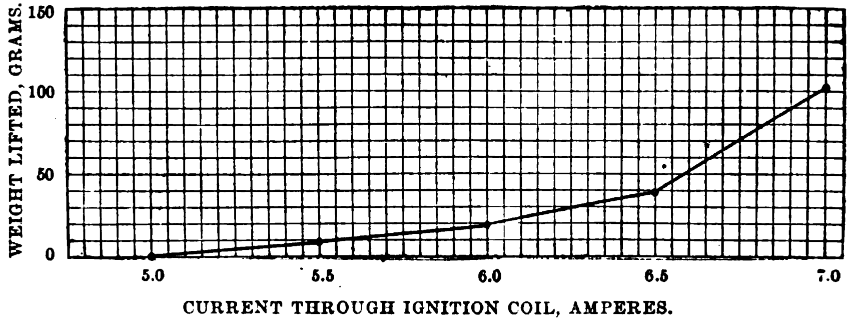

FIGURE 9.—Relative inflammability of coal No. 10628, Raleigh County, W. Va. Moisture, 0.59 per cent; volatile matter, 18.77 per cent; fixed carbon, 77.01 per cent; ash, 3.63 per cent; sulphur, 0.74 per cent.

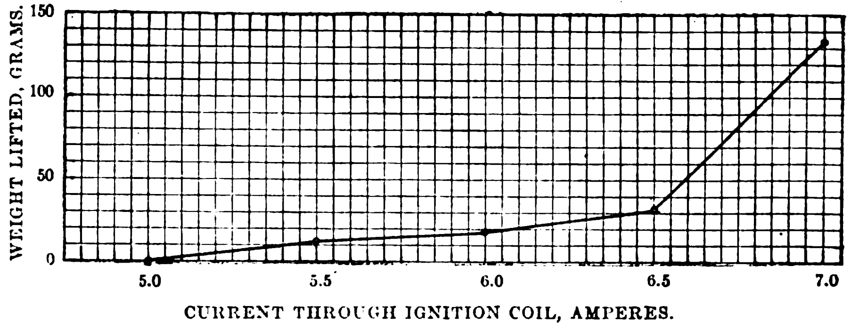

FIGURE 10.—Relative inflammability of coal No. 10623, Fayette County, W. Va. Moisture, 0.83 per cent; volatile matter, 25.45 per cent; fixed carbon, 70.91 per cent; ash, 2.81 per cent; sulphur, 0.60 per cent.

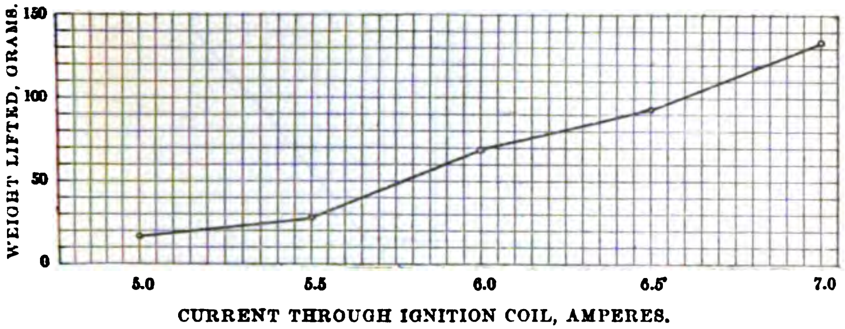

FIGURE 11.—Relative inflammability of coal No. 10732, El Paso County, Colo. Moisture, 15.57 per cent; volatile matter, 32.77 per cent; fixed carbon, 34.12 per cent; ash, 17.54 per cent; sulphur, 0.38 per cent.

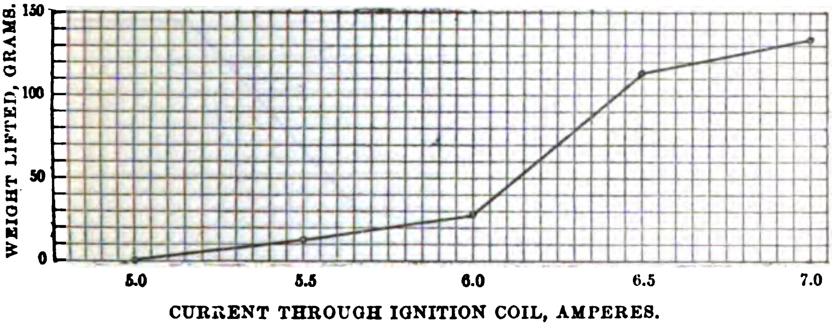

FIGURE 12.—Relative inflammability of coal No. 11135, Las Animas County, Colo. Moisture, 1 per cent; volatile matter, 28.90 per cent; fixed carbon, 55.78 per cent; ash, 14.32 per cent; sulphur, 0.63 per cent.

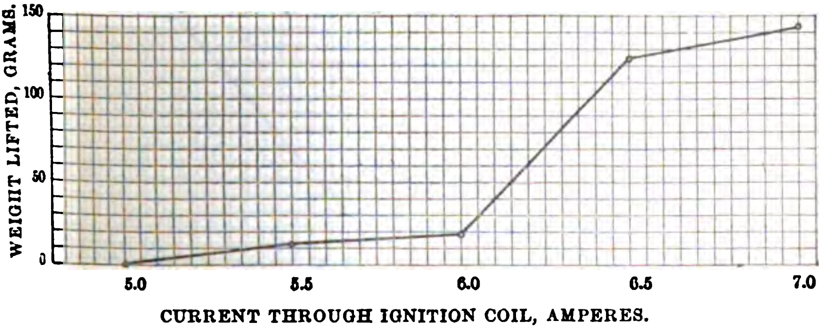

FIGURE 13.—Relative inflammability of coal No. 11134, Las Animas County, Colo. Moisture, 1.28 per cent; volatile matter, 29.39 per cent; fixed carbon, 56.00 per cent; ash, 13.33 per cent; sulphur, 0.57 per cent.

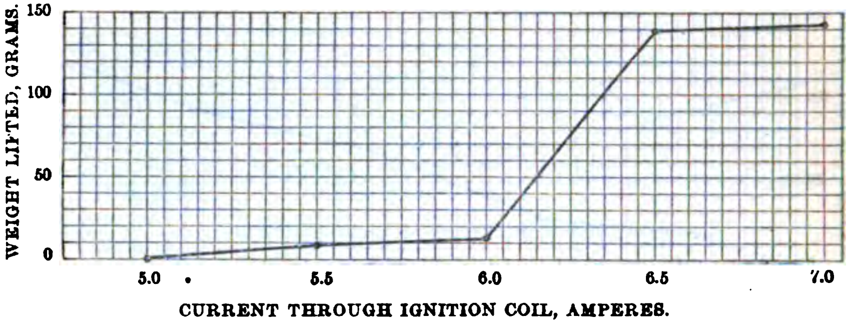

Figure 14.—Relative inflammability of coal No. 11107, Delta County, Colo. Moisture, 2.57 per cent; volatile matter, 31.41 per cent; fixed carbon, 48.59 per cent; ash, 17.43 per cent; sulphur, 1.90 per cent.

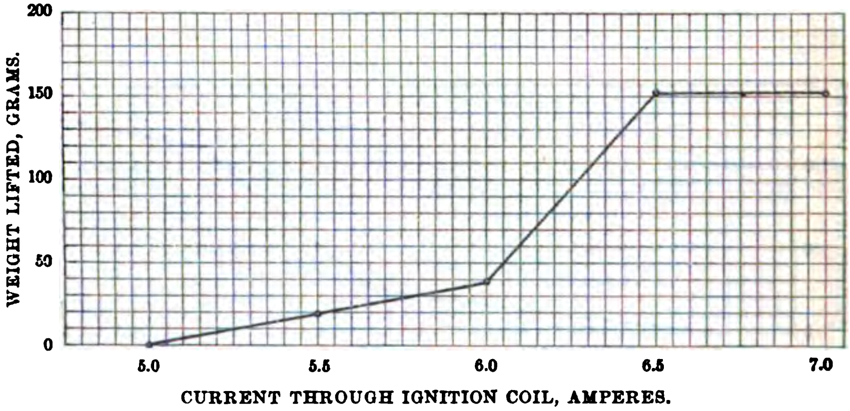

Figure 15.—Relative inflammability of coal No. 10692, Rhea County, Tenn. Moisture, 1.07 per cent; volatile matter, 29.05 per cent; fixed carbon, 57.98 per cent; ash, 11.90 per cent; sulphur, 1.80 per cent.

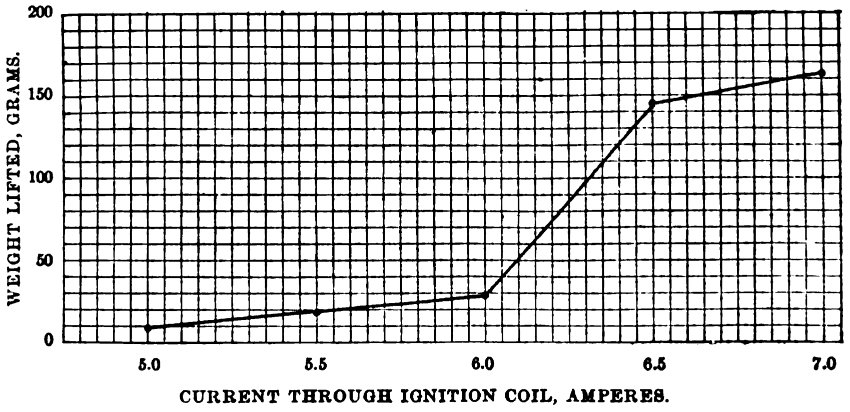

Figure 16.—Relative inflammability of coal No. 12198, Las Animas County, Colo. Moisture, 1.22 per cent; volatile matter, 29.23 per cent; fixed carbon, 52.77 per cent; ash, 16.78 per cent; sulphur, 0.56 per cent.

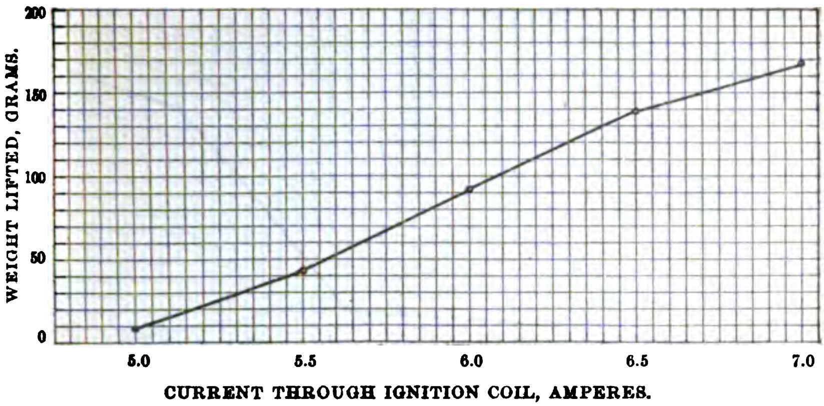

FIGURE 17.—Relative inflammability of coal No. 11059, Johnson County, Wyo. Moisture, 13.63 per cent; volatile matter, 32.61 per cent; fixed carbon, 38.19 per cent; ash, 15.57 per cent; sulphur, 1.60 per cent.

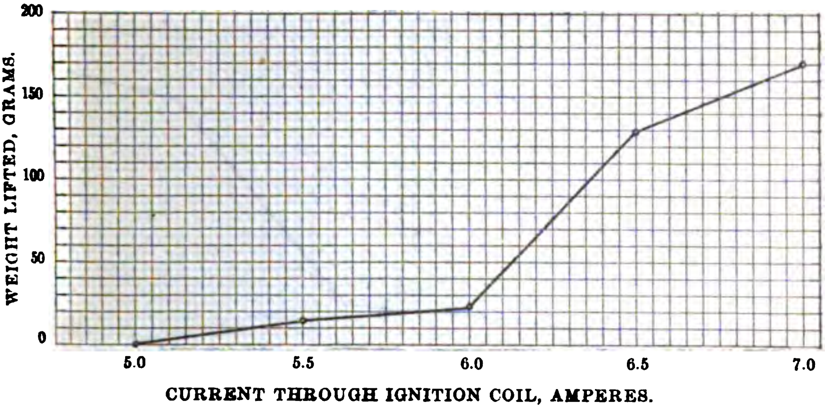

FIGURE 18.—Relative inflammability of coal No. 12086, Jefferson County, Ala. Moisture, 1.15 per cent; volatile matter, 27.32 per cent; fixed carbon, 60.32 per cent; ash, 11.21 per cent; sulphur, 0.80 per cent.

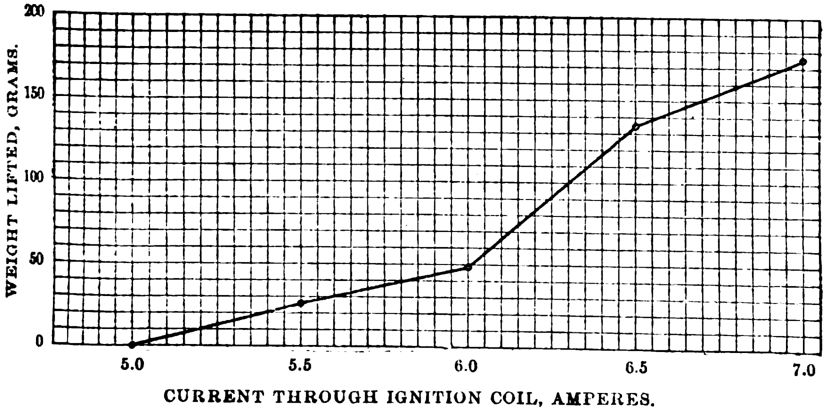

FIGURE 19.—Relative inflammability of coal No. 11443, Las Animas County, Colo. Moisture, 1.24 per cent; volatile matter, 35.08 per cent; fixed carbon, 53.14 per cent; ash, 10.54 per cent; sulphur, 0.56 per cent.

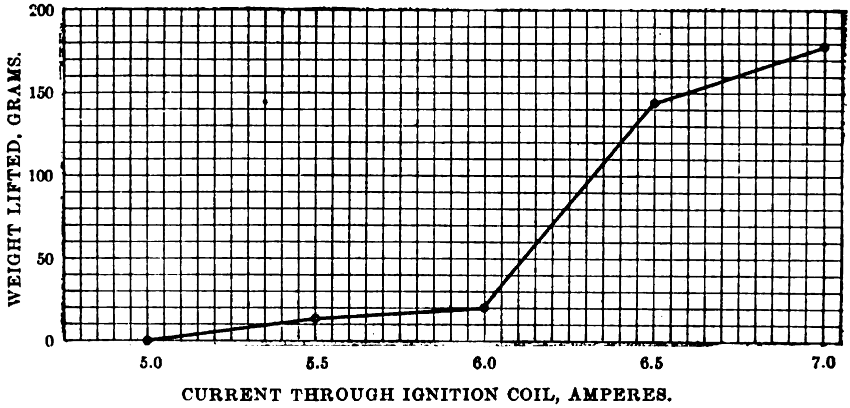

FIGURE 20.—Relative inflammability of coal No. 10801, Bledsoe County, Tenn. Moisture, 1.06 per cent; volatile matter, 27.29 per cent; fixed carbon, 64.21 per cent; ash, 7.44 per cent; sulphur, 0.53 per cent.

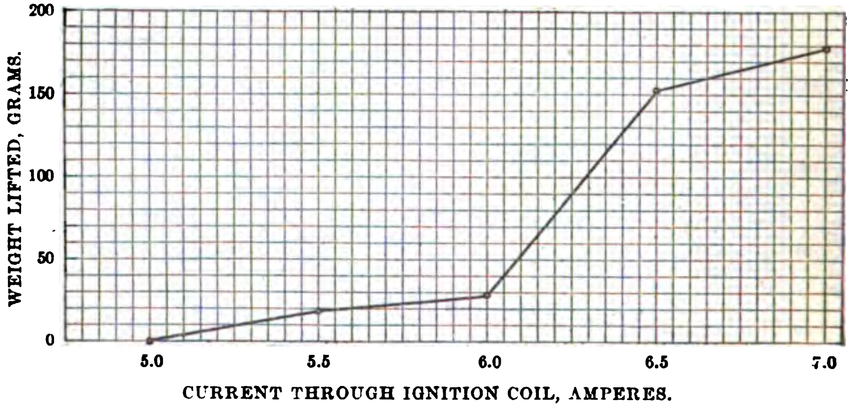

FIGURE 21.—Relative inflammability of coal No. 11163, Washington County, Pa. Moisture, 1.05 per cent; volatile matter, 34.12 per cent; fixed carbon, 58.34 per cent; ash, 6.49 per cent; sulphur, 1.13 per cent.

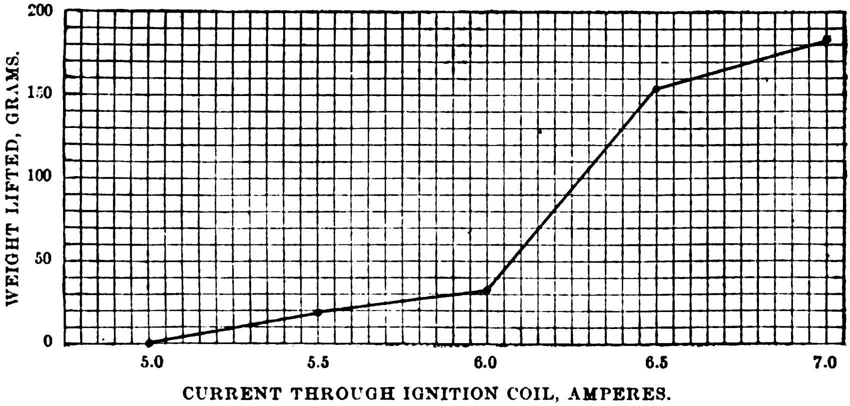

FIGURE 22.—Relative inflammability of coal No. 11170, Washington County, Pa. Moisture, 1.07 per cent; volatile matter, 34.55 per cent; fixed carbon, 58.51 per cent; ash, 5.87 per cent; sulphur, 1.07 per cent.

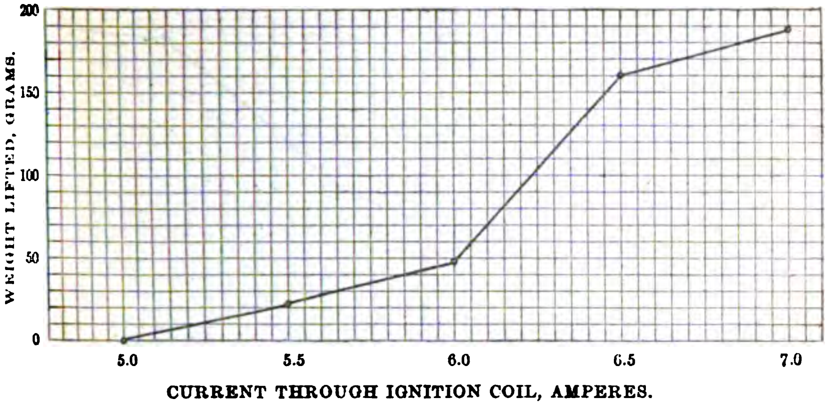

FIGURE 23.—Relative inflammability of coal No. 11156, Marion County, W. Va. Moisture, 1.22 per cent; volatile matter, 36.39 per cent; fixed carbon, 53.58 per cent; ash, 8.81 per cent; sulphur, 2.06 per cent.

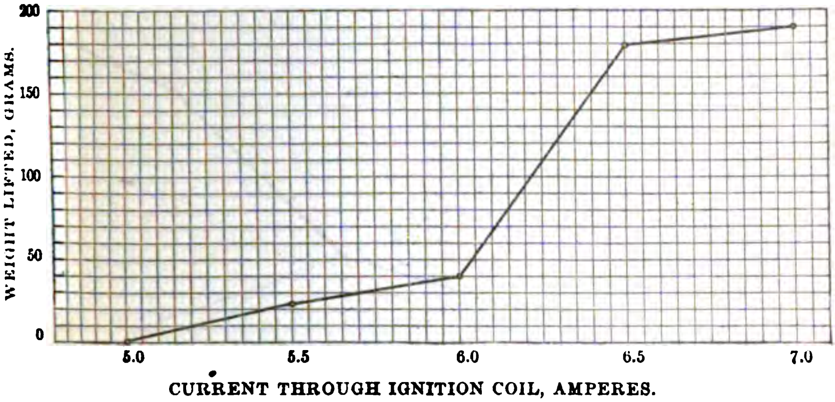

FIGURE 24.—Relative inflammability of coal No. 12029, Las Animas County, Colo. Moisture, 0.83 per cent; volatile matter, 32.77 per cent; fixed carbon, 49.09 per cent; ash, 17.31 per cent; sulphur, 0.94 per cent.

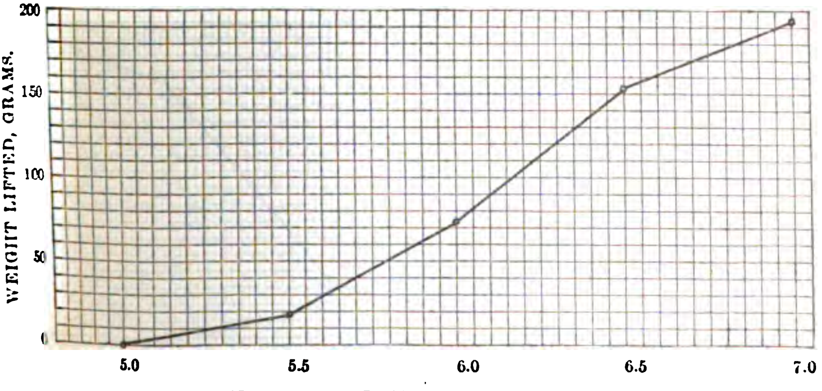

FIGURE 25.—Relative inflammability of coal No. 10741, El Paso County, Colo. Moisture, 11.31 per cent; volatile matter, 31.36 per cent; fixed carbon, 32.98 per cent; ash, 24.35 per cent; sulphur, 0.43 per cent.

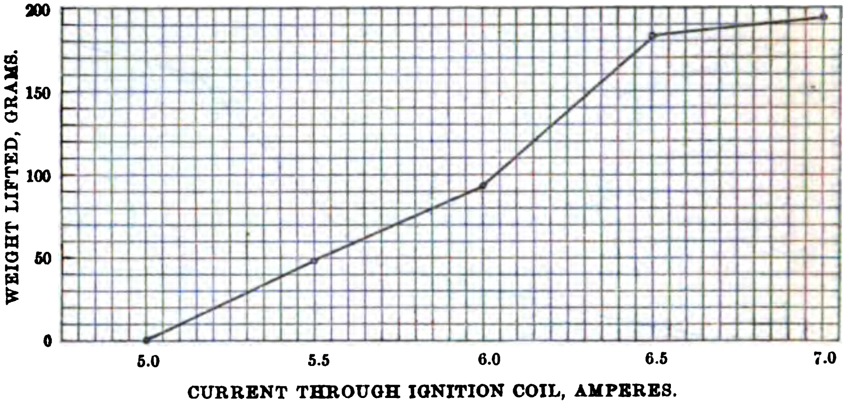

FIGURE 26.—Relative inflammability of coal No. 10713, Uinta County, Utah. Moisture, 7.75 per cent; volatile matter, 39.27 per cent; fixed carbon, 44.65 per cent; ash, 8.33 per cent; sulphur, 2.30 per cent.

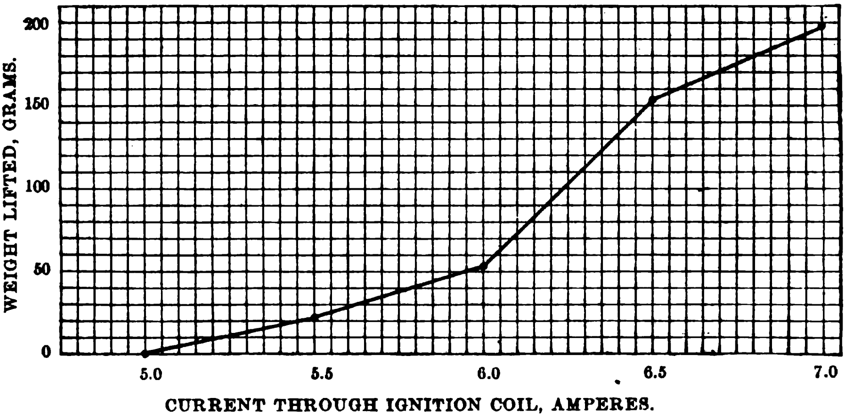

FIGURE 27.—Relative inflammability of coal No. 11433, Marion County, W. Va. Moisture, 1.47 per cent; volatile matter, 35.54 per cent; fixed carbon, 57.30 per cent; ash, 5.69 per cent; sulphur, 0.68 per cent.

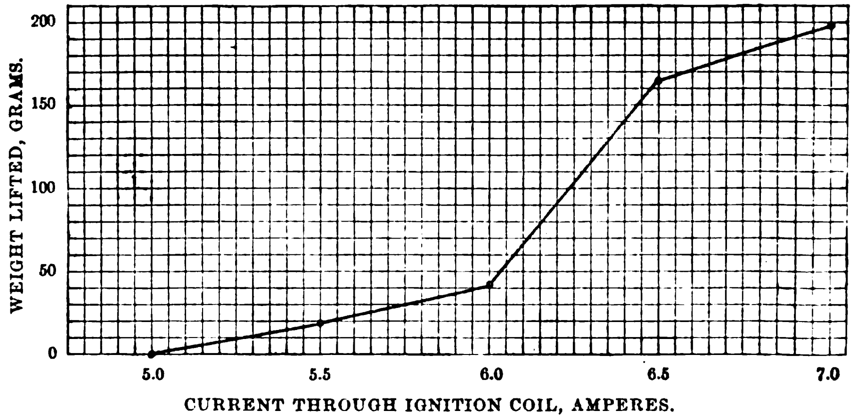

FIGURE 28.—Relative inflammability of coal No. 10916, Bledsoe County, Tenn. Moisture, 1.68 per cent; volatile matter, 29.92 per cent; fixed carbon, 61.91 per cent; ash, 6.49 per cent; sulphur, 0.53 per cent.

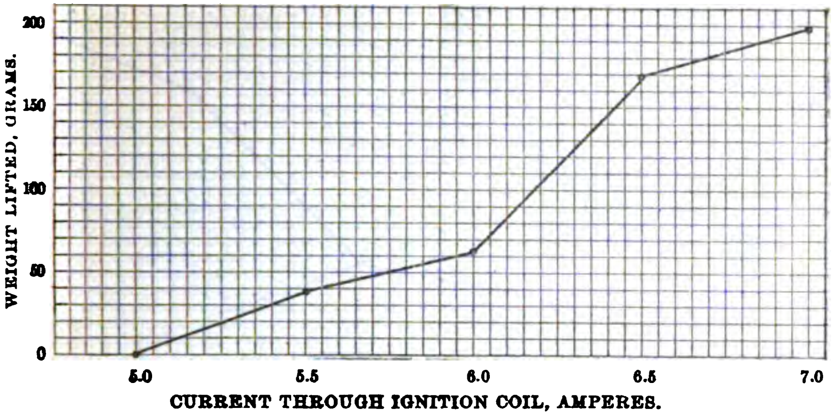

FIGURE 29.—Relative inflammability of coal No. 10959, Madison County, Ill. Moisture, 7.52 per cent; volatile matter, 38.52 per cent; fixed carbon, 43.93 per cent; ash, 10.03 per cent; sulphur, 3.89 per cent.

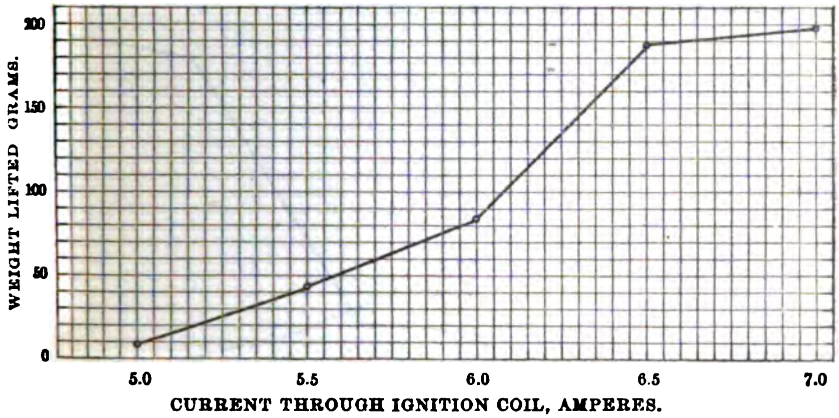

FIGURE 30.—Relative inflammability of coal No. 11006, Valley County, Mont. Moisture, 9.36 per cent; volatile matter, 41.40 per cent; fixed carbon, 40.59 per cent; ash, 8.65 per cent; sulphur, 0.62 per cent.

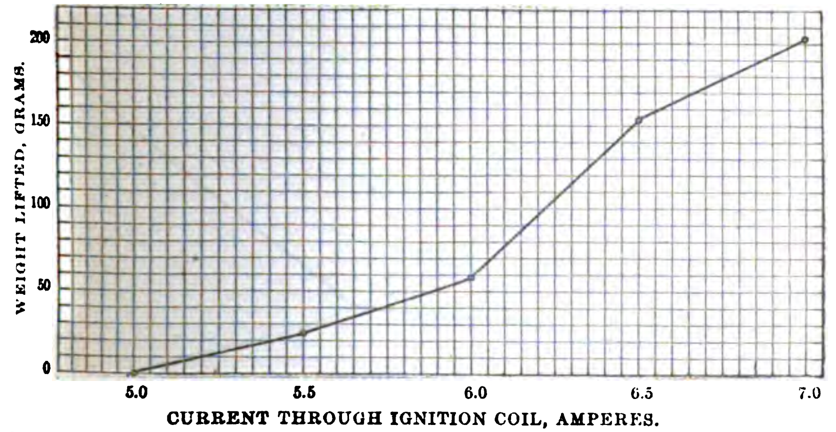

FIGURE 31.—Relative inflammability of coal No. 11382, Matanuska coal fields, Alaska. Moisture, 4.76 per cent; volatile matter, 36.00 per cent; fixed carbon, 53.85 per cent; ash, 5.39 per cent; sulphur, 0.24 per cent.

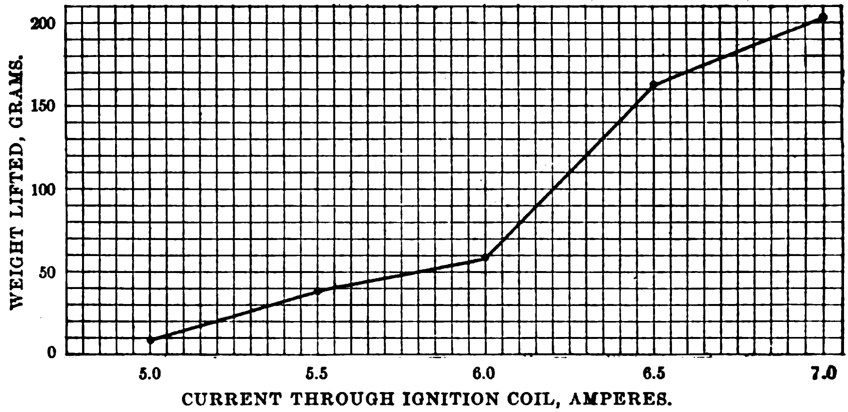

FIGURE 32.—Relative inflammability of coal No. 10997, Wasatch County, Utah. Moisture, 10.37 per cent; volatile matter, 39.68 per cent; fixed carbon, 46.75 per cent; ash, 3.20 per cent; sulphur, 0.74 per cent.

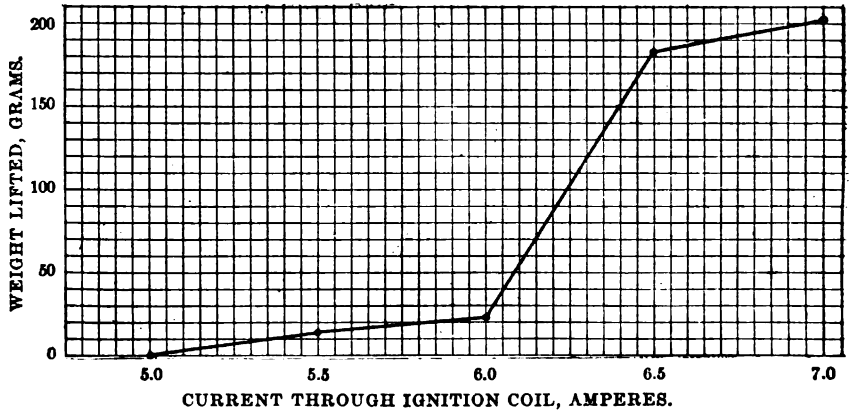

FIGURE 33.—Relative inflammability of coal No. 11592, Pittsburg County, Okla. Moisture, 1.52 per cent; volatile matter, 33.28 per cent; fixed carbon, 58.04 per cent; ash, 7.16 per cent; sulphur, 0.50 per cent.

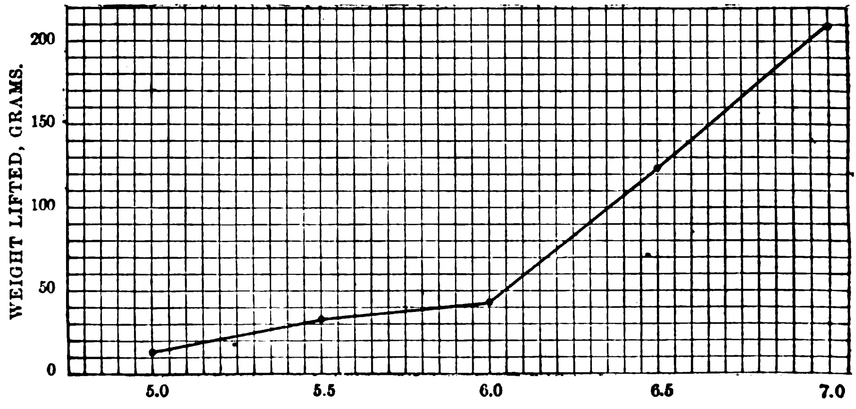

FIGURE 34.—Relative inflammability of coal No. 12025, Las Animas County, Colo. Moisture, 0.77 per cent volatile matter, 31.58 per cent; fixed carbon, 57.57 per cent; ash, 10.08 per cent; sulphur, 0.60 per cent.

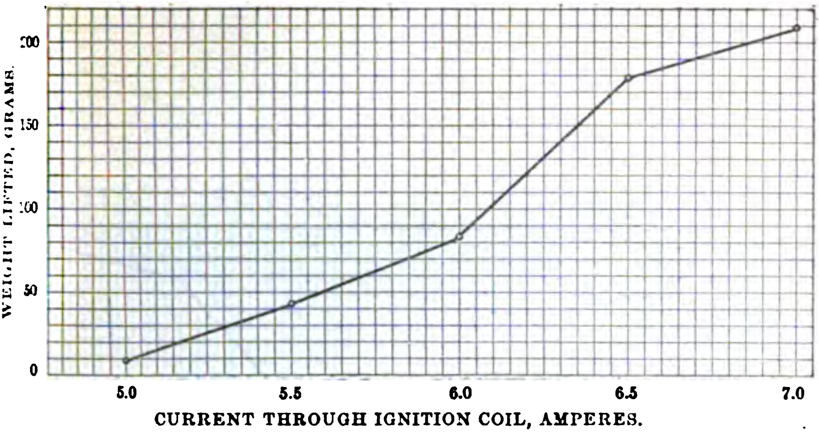

FIGURE 35.—Relative inflammability of coal No. 10575, Pierce County, Wash. Moisture, 1.68 per cent; volatile matter, 35.24 per cent; fixed carbon, 48.02 per cent; ash, 15.06 per cent; sulphur, 0.35 per cent.

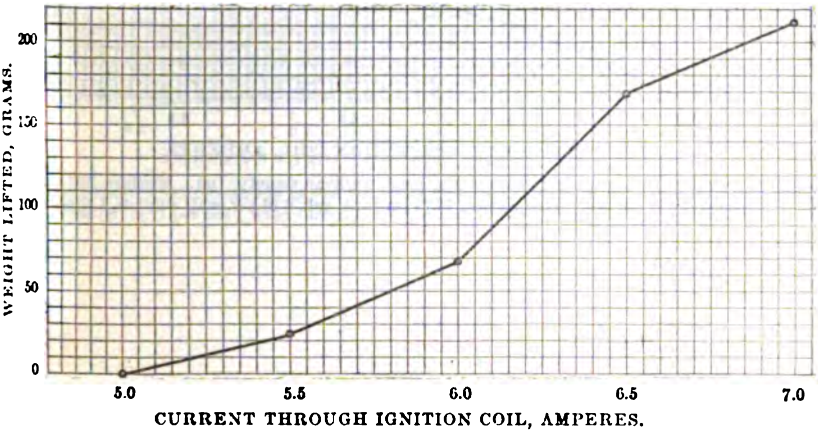

FIGURE 36.—Relative inflammability of coal No. 11465, Sweetwater County, Wyo. Moisture, 4.64 per cent; volatile matter, 39.96 per cent; fixed carbon, 51.76 per cent; ash, 3.64 per cent; sulphur, 1.07 per cent.

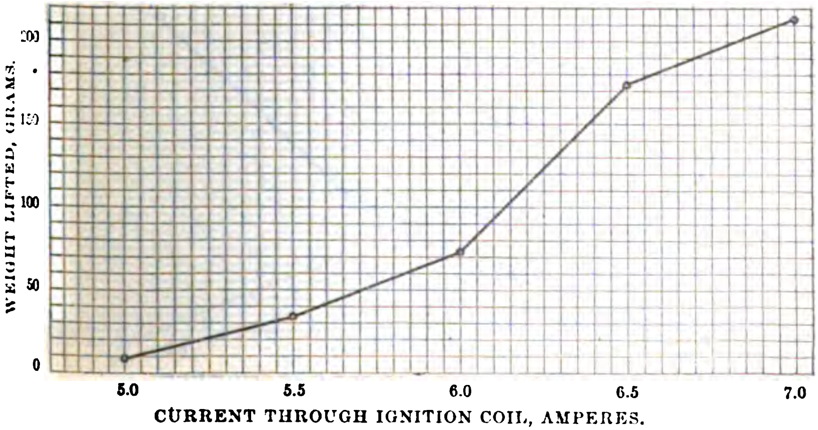

FIGURE 37.—Relative inflammability of coal No. 10556, Allegheny County, Pa. Moisture, 1.90 per cent; volatile matter, 35.59 per cent; fixed carbon, 57.87 per cent; ash, 4.64 per cent; sulphur, 0.52 per cent.

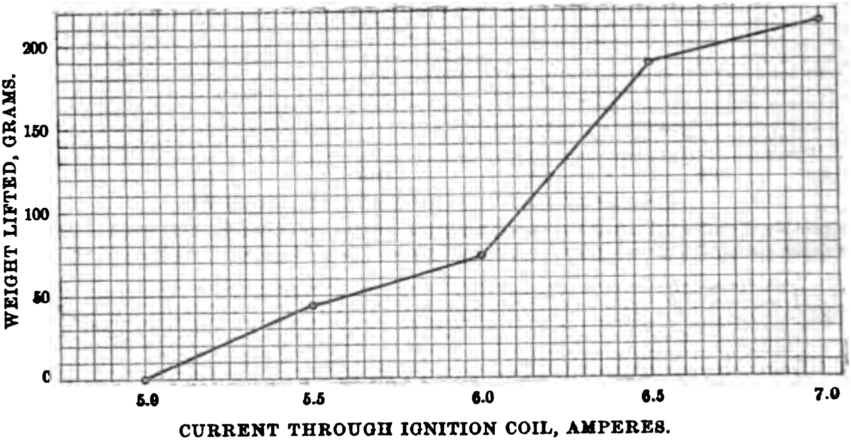

FIGURE 38.—Relative inflammability of coal No. 10961, Sullivan County, Ind. Moisture, 7.37 per cent; volatile matter, 34.81 per cent; fixed carbon, 51.79 per cent; ash, 6.03 per cent; sulphur, 1.17 per cent.

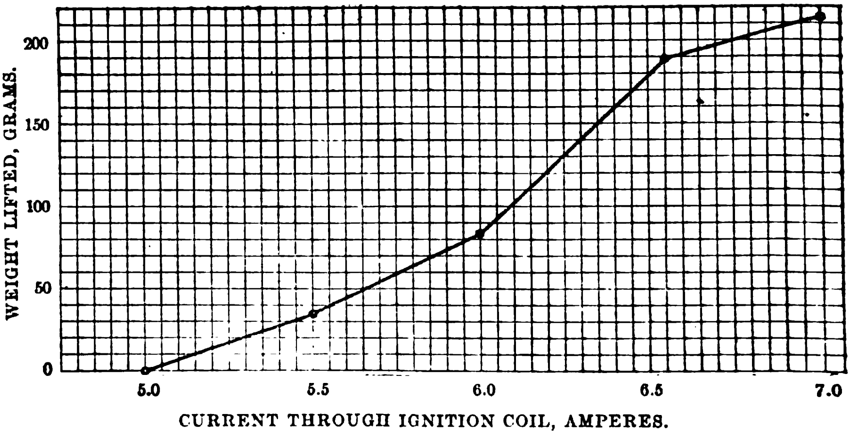

FIGURE 39.—Relative inflammability of coal No. 11354, Montgomery County, Ill. Moisture, 6.48 per cent; volatile matter, 36.27 per cent; fixed carbon, 44.60 per cent; ash, 12.65 per cent; sulphur, 4.05 per cent.

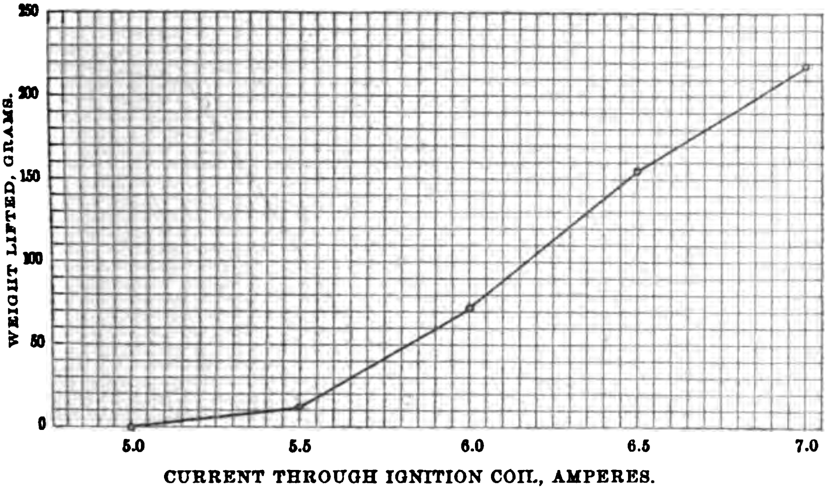

FIGURE 40.—Relative inflammability of coal No. 11184, Crawford County, Kans. Moisture, 1.50 per cent; volatile matter, 34.71 per cent; fixed carbon, 54.37 per cent; ash, 9.42 per cent; sulphur, 5.12 per cent.

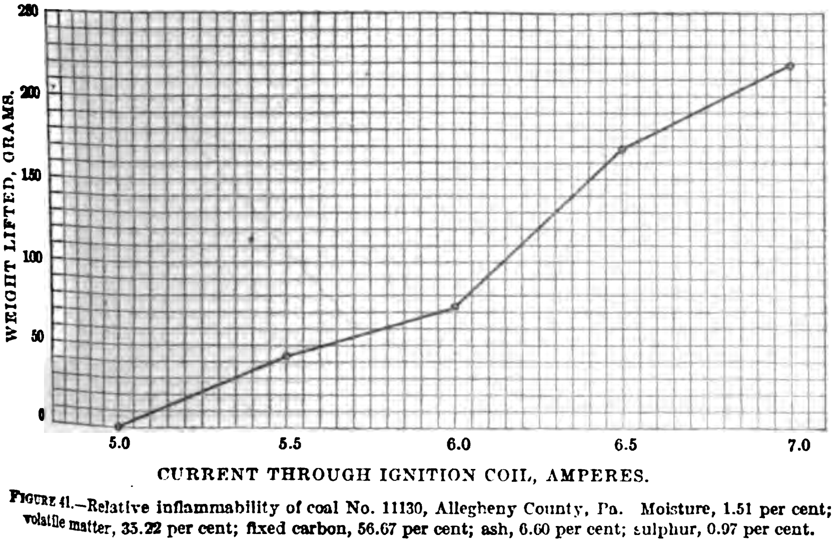

FIGURE 41.—Relative inflammability of coal No. 11130, Allegheny County, Pa. Moisture, 1.51 per cent; volatile matter, 35.22 per cent; fixed carbon, 56.67 per cent; ash, 6.60 per cent; sulphur, 0.97 per cent.

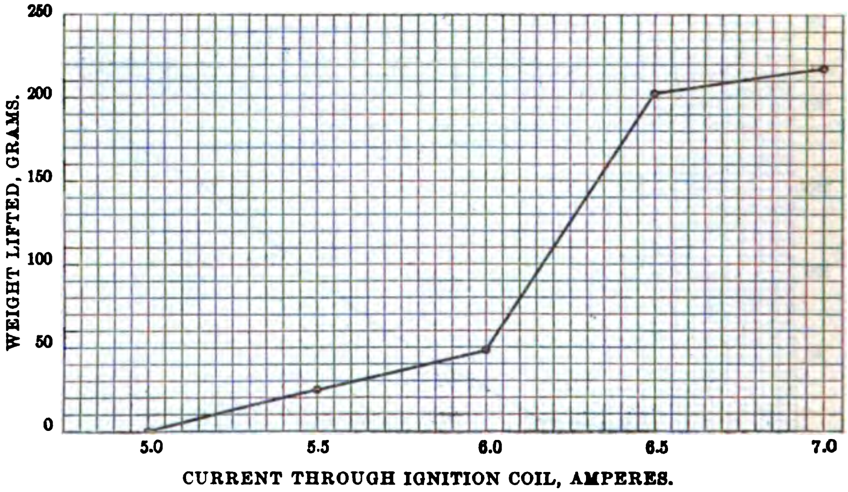

FIGURE 42.—Relative inflammability of coal No. 11180, Barton County, Mo. Moisture, 1.28 per cent; volatile matter, 33.47 per cent; fixed carbon, 55.91 per cent; ash, 9.34 per cent; sulphur, 3.78 per cent.

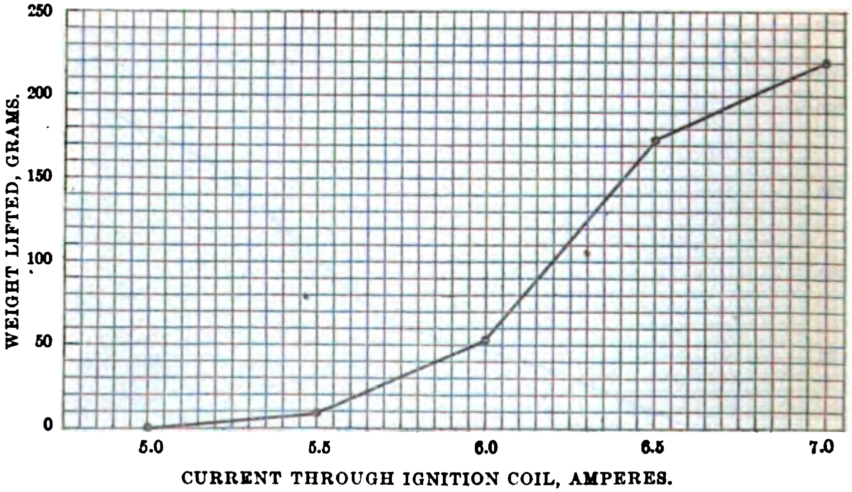

FIGURE 43.—Relative inflammability of coal No. 11188, Barton County, Mo. Moisture, 1.64 per cent; volatile matter, 32.37 per cent; fixed carbon, 53.99 per cent; ash, 12.00 per cent; sulphur, 5.22 per cent.

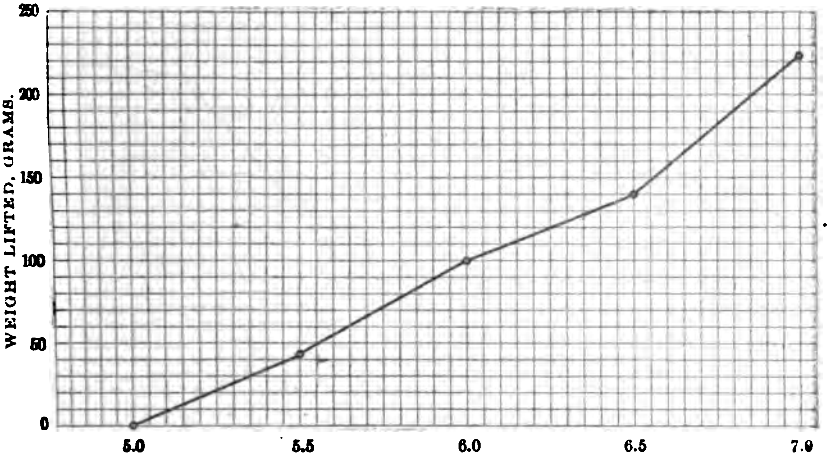

FIGURE 44.—Relative inflammability of coal No. 12028, Las Animas County, Colo. Moisture, 1.27 per cent; volatile matter, 33.18 per cent; fixed carbon, 56.16 per cent; ash, 9.39 per cent; sulphur, 0.63 per cent.

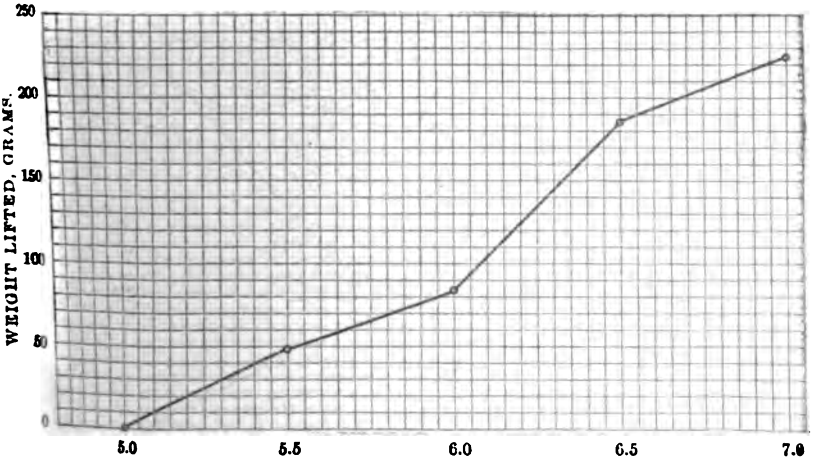

FIGURE 45.—Relative inflammability of coal No. 10960, Sullivan County, Ind. Moisture, 7.20 per cent; volatile matter, 36.61 per cent; fixed carbon, 50.81 per cent; ash, 5.38 per cent; sulphur, 0.88 per cent.

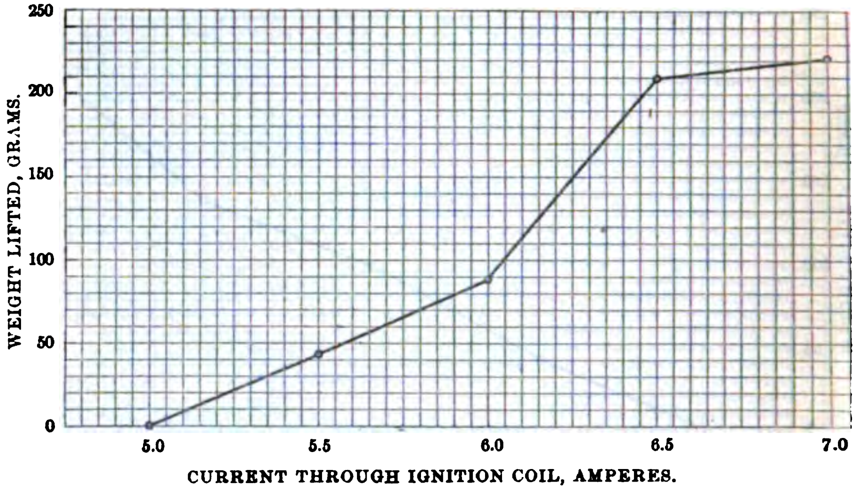

FIGURE 46.—Relative inflammability of coal No. 12004, Pike County, Ky. Moisture, 1.45 per cent; volatile matter, 35.66 per cent; fixed carbon, 60.18 per cent; ash, 2.71 per cent; sulphur, 0.57 per cent.

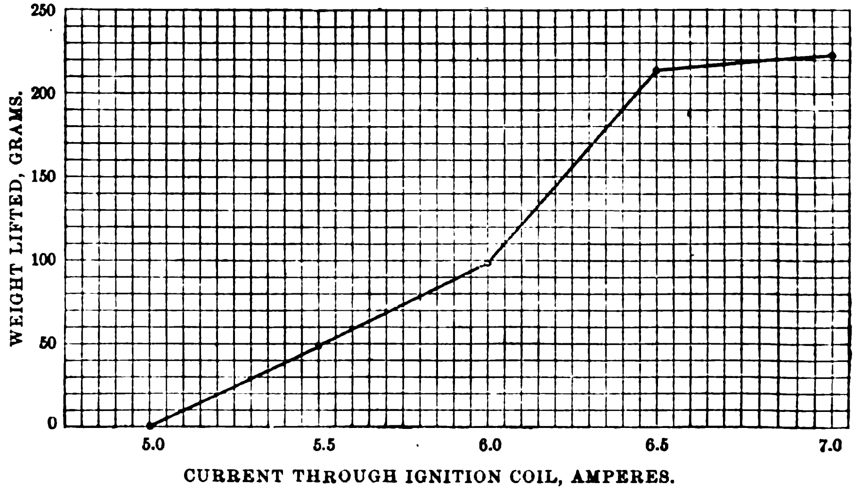

FIGURE 47.—Relative inflammability of coal No. 11984, Allegheny County, Pa. Moisture, 1.70 per cent; volatile matter, 35.73 per cent; fixed carbon, 56.32 per cent; ash, 6.25 per cent; sulphur, 1.49 per cent.

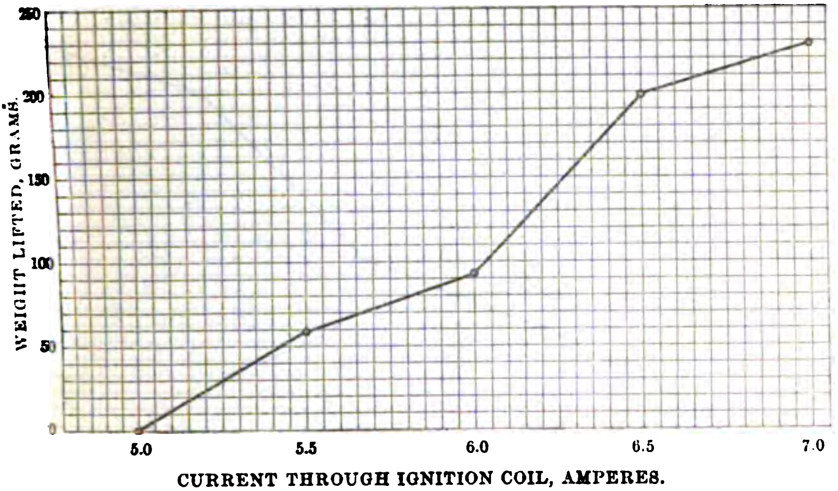

FIGURE 48.—Relative inflammability of coal No. 10739, Russell County, Va. Moisture, 0.78 per cent; volatile matter, 36.37 per cent; fixed carbon, 57.45 per cent; ash, 5.40 per cent; sulphur, 0.58 per cent.

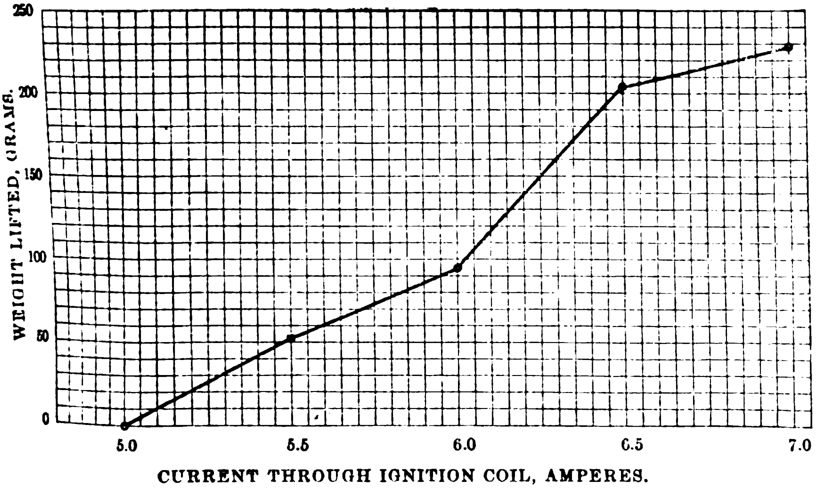

FIGURE 49.—Relative inflammability of coal No. 10736, Russell County, Va. Moisture, 0.98 per cent; volatile matter, 35.60 per cent; fixed carbon, 57.54 per cent; ash, 5.88 per cent; sulphur, 0.60 per cent.

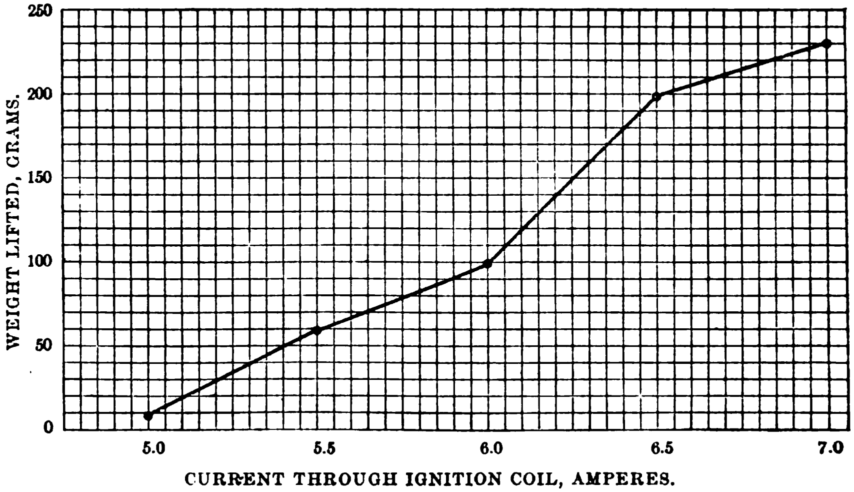

Figure 50.—Relative inflammability of coal No. 10845, Allegheny County, Pa. Moisture, 1.81 per cent; volatile matter, 35.76 per cent; fixed carbon, 56.41 per cent; ash, 6.02 per cent; sulphur, 1.20 per cent.

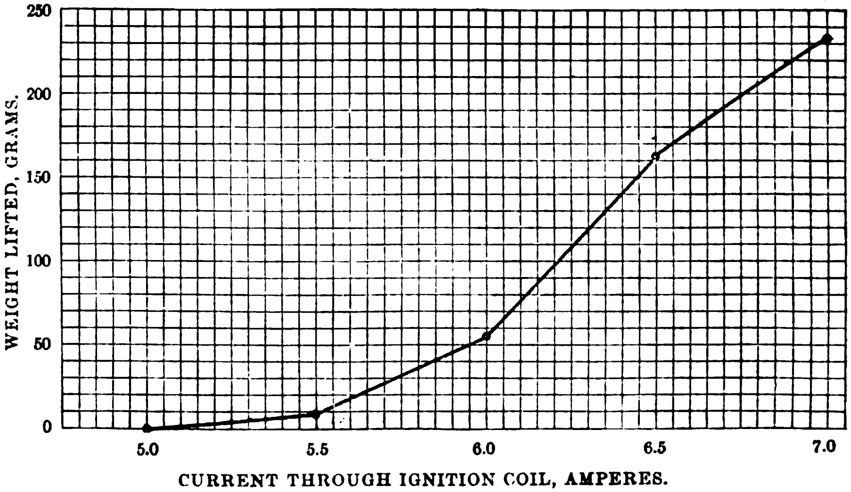

Figure 51.—Relative inflammability of coal No. 11569, Pittsburg County, Okla. Moisture, 1.41 per cent; volatile matter, 34.44 per cent; fixed carbon, 58.87 per cent; ash, 5.28 per cent; sulphur, 0.55 per cent.

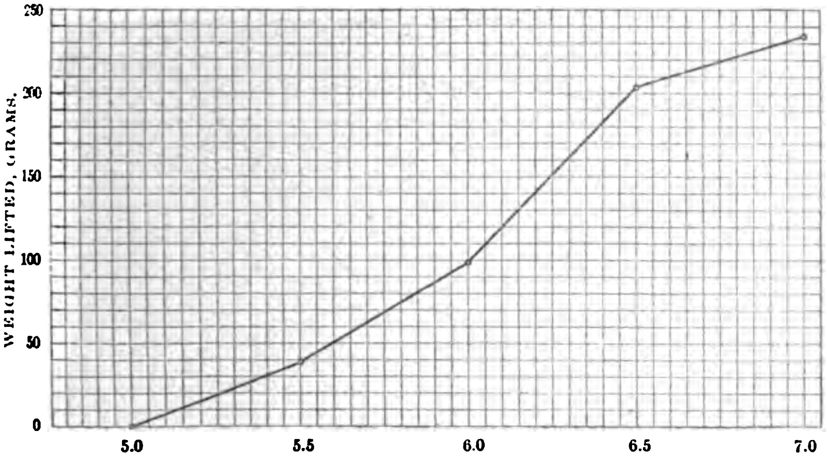

FIGURE 52.—Relative inflammability of coal No. 11460, Sweetwater County, Wyo. Moisture, 3.88 per cent; volatile matter, 39.55 per cent; fixed carbon, 52.81 per cent; ash, 3.76 per cent; sulphur, 1.11 per cent.

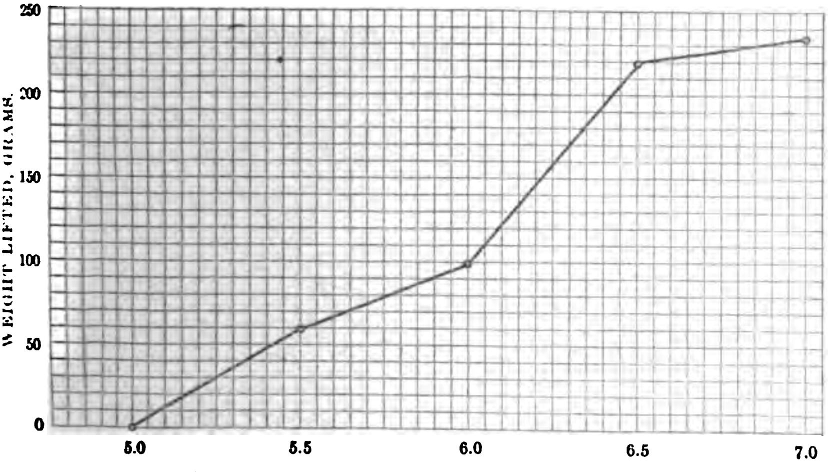

FIGURE 53.—Relative inflammability of coal No. 11985, Allegheny County, Pa. Moisture, 1.67 per cent; volatile matter, 35.85 per cent; fixed carbon, 55.73 per cent; ash, 6.75 per cent; sulphur, 1.51 per cent.

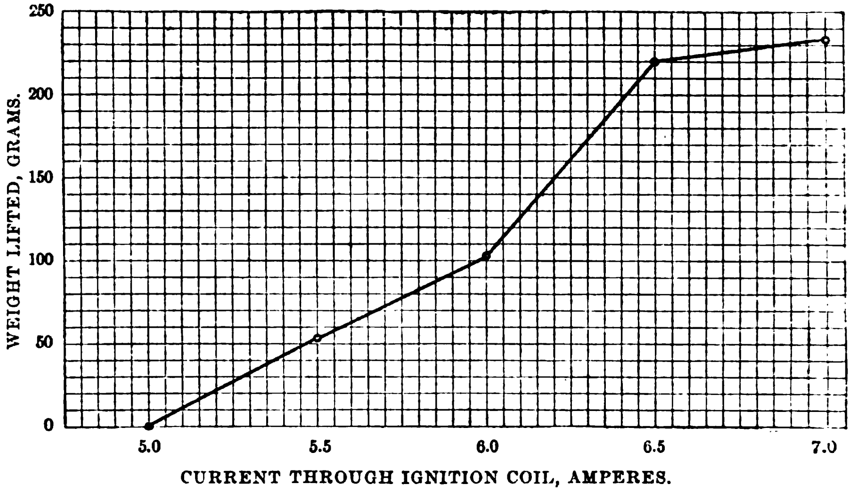

Figure 54.—Relative inflammability of coal No. 11983, Allegheny County, Pa. Moisture, 1.83 per cent; volatile matter, 35.62 per cent; fixed carbon, 56.69 per cent; ash, 5.86 per cent; sulphur, 1.19 per cent.

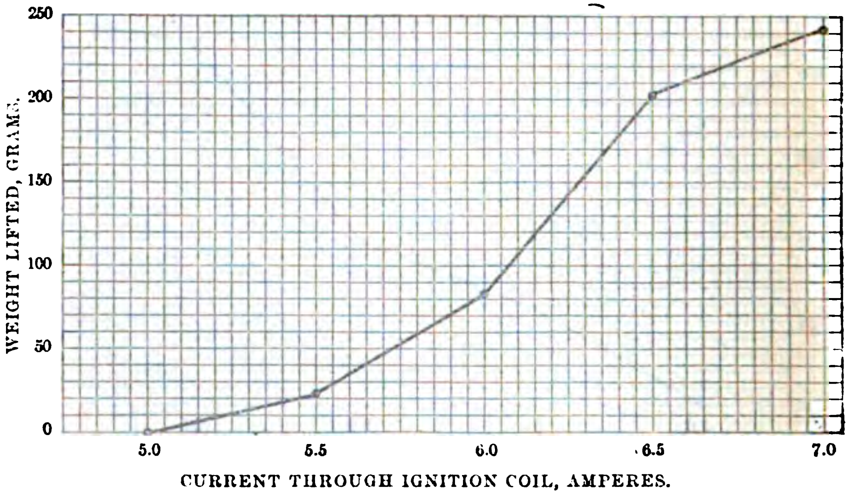

Figure 55.—Relative inflammability of coal No. 11919, Pittsburg County, Okla. Moisture, 1.89 per cent; volatile matter, 35.69 per cent; fixed carbon, 58.00 per cent; ash, 4.42 per cent; sulphur, 0.63 per cent.

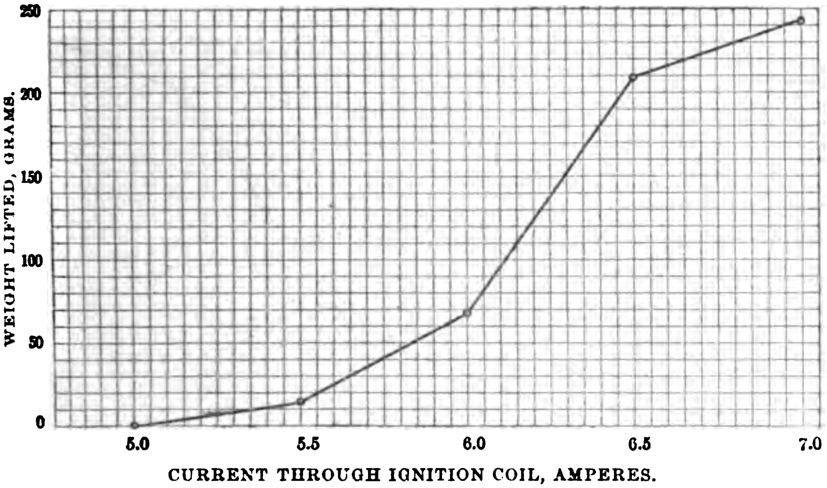

FIGURE 56.—Relative inflammability of coal No. 11594, Pittsburg County, Okla. Moisture, 1.60 per cent; volatile matter, 34.06 per cent; fixed carbon, 59.24 per cent; ash, 5.10 per cent; sulphur, 0.50 per cent.

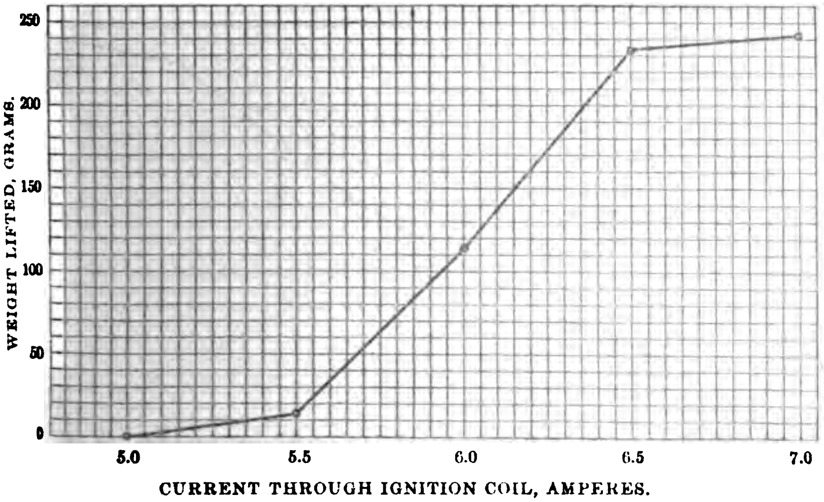

FIGURE 57.—Relative inflammability of coal No. 11068, Wasatch County, Utah. Moisture, 14.35 per cent; volatile matter, 39.24 per cent; fixed carbon, 39.83 per cent; ash, 6.58 per cent; sulphur, 0.73 per cent.

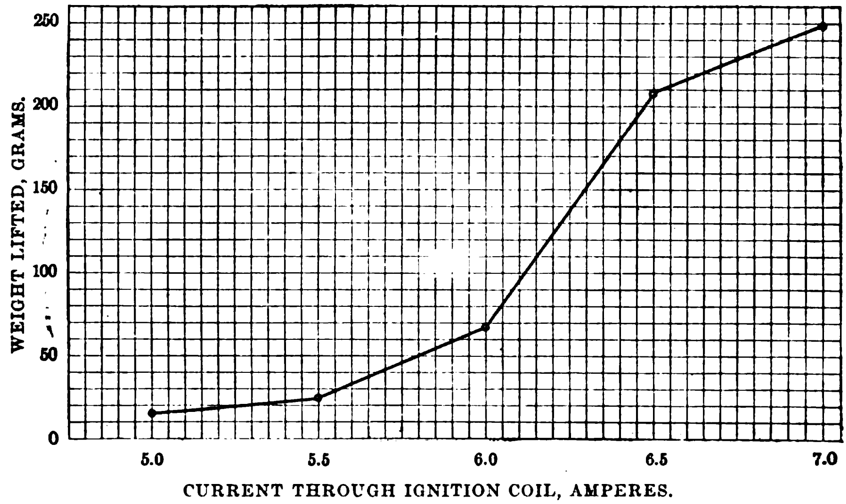

FIGURE 58.—Relative inflammability of coal No. 11930, Las Animas County, Colo. Moisture, 0.86 per cent; volatile matter, 31.07 per cent; fixed carbon, 57.39 per cent; ash, 10.68 per cent; sulphur, 0.62 per cent.

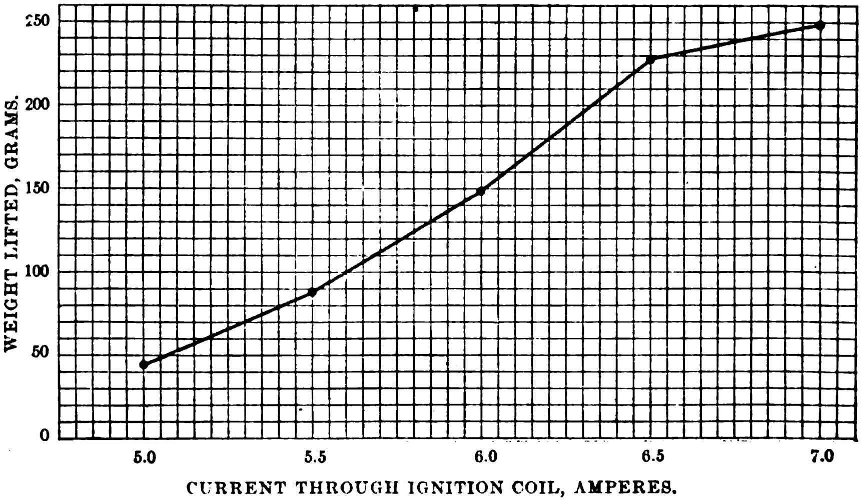

FIGURE 59.—Relative inflammability of coal No. 10189, Huerfano County, Colo. Moisture, 4.83 per cent; volatile matter, 37.81 per cent; fixed carbon, 49.61 per cent; ash, 7.75 per cent; sulphur, 0.57 per cent.

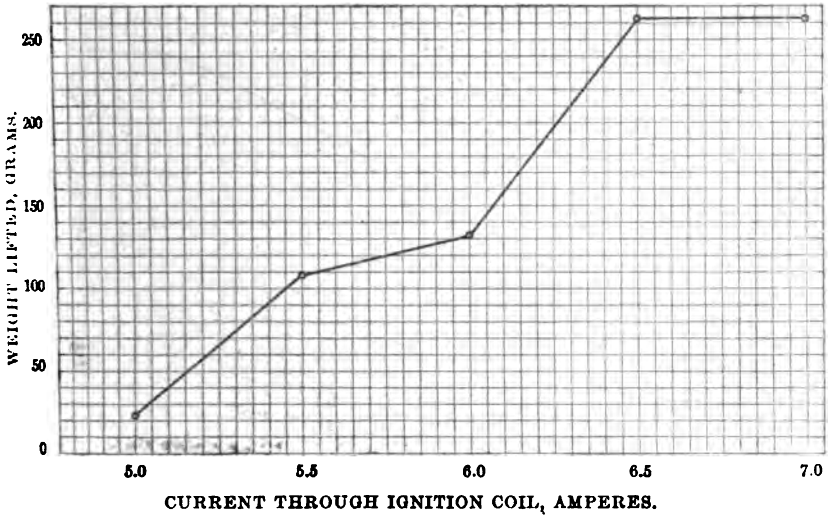

FIGURE 60.—Relative inflammability of coal No. 10909, Carbon County, Utah. Moisture, 3.33 per cent; volatile matter, 41.79 per cent; fixed carbon, 47.76 per cent; ash, 7.12 per cent; sulphur, 0.57 per cent.

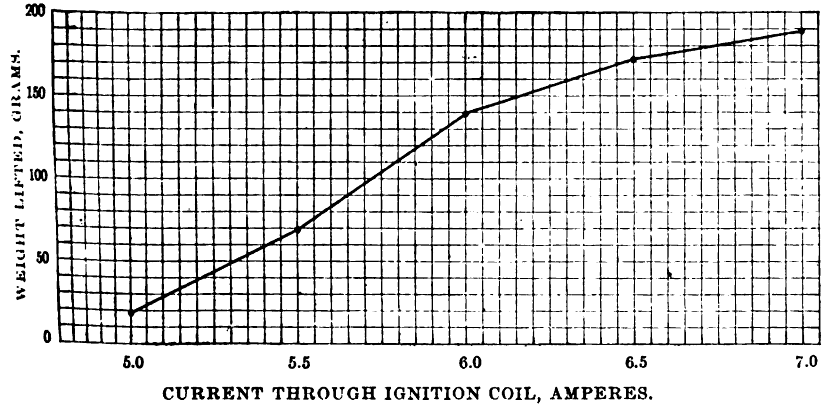

FIGURE 61.—Relative inflammability of coal No. 10671, Natrona County, Wyo. Moisture, 12.21 per cent; volatile matter, 34.22 per cent; fixed carbon, 46.89 per cent; ash, 6.68 per cent; sulphur, 0.59 per cent.

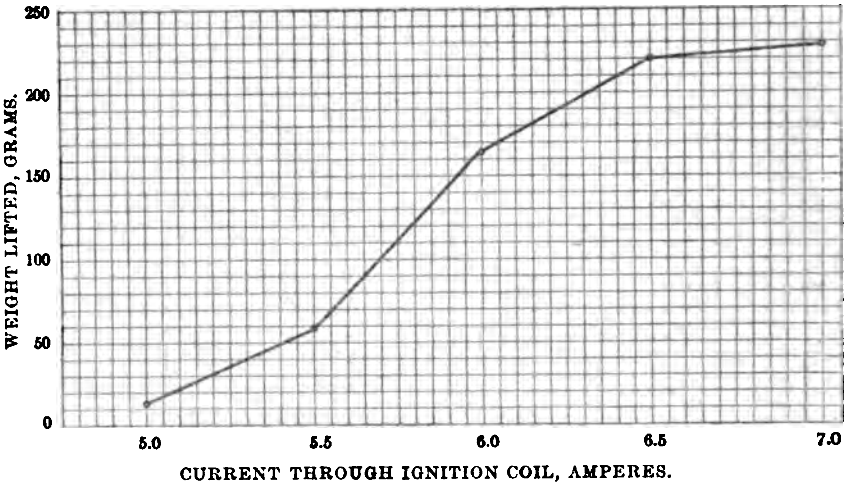

FIGURE 62.—Relative inflammability of coal No. 10899, Valley County, Mont. Moisture, 11.18 per cent; volatile matter, 38.82 per cent; fixed carbon, 42.70 per cent; ash, 7.30 per cent; sulphur, 0.54 per cent.

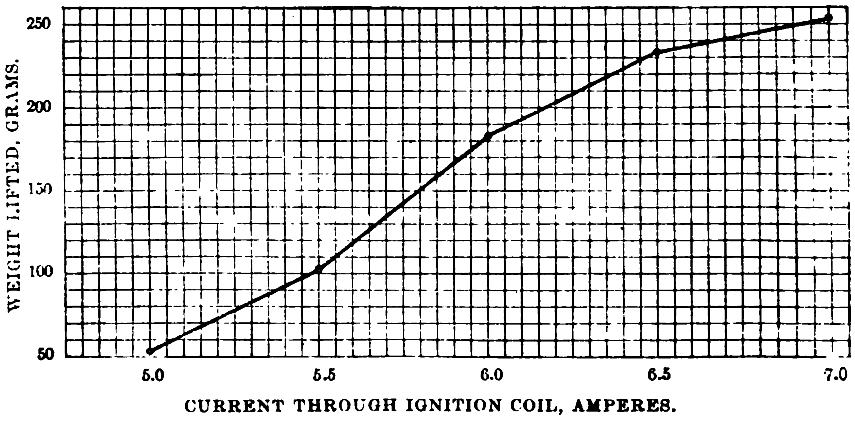

FIGURE 63.—Relative inflammability of coal No. 10998, Wasatch County, Utah. Moisture, 6.14 per cent; volatile matter, 42.29 per cent; fixed carbon, 45.04 per cent; ash, 6.53 per cent; sulphur, 0.90 per cent.

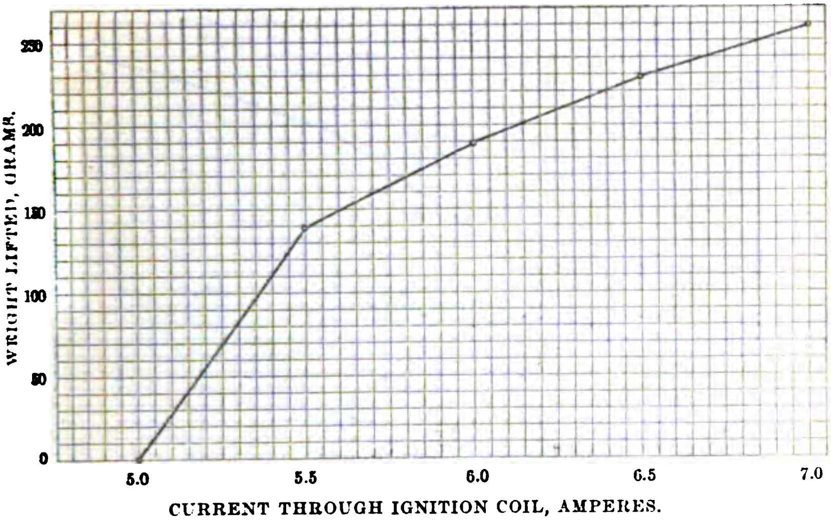

FIGURE 64.—Relative inflammability of coal No. 10810, Sheridan County, Wyo. Moisture, 15.17 per cent; volatile matter, 35.31 per cent; fixed carbon, 45.82 per cent; ash, 3.70 per cent; sulphur, 0.40 per cent.

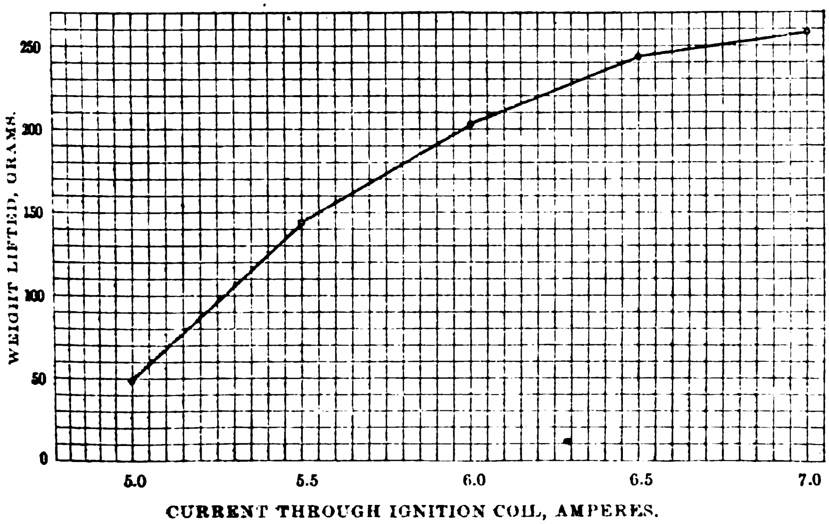

FIGURE 65.—Relative inflammability of coal No. 10827, Johnson County, Wyo. Moisture, 15.52 per cent; volatile matter, 39.34 per cent; fixed carbon, 39.43 per cent; ash, 5.71 per cent; sulphur, 0.64 per cent.

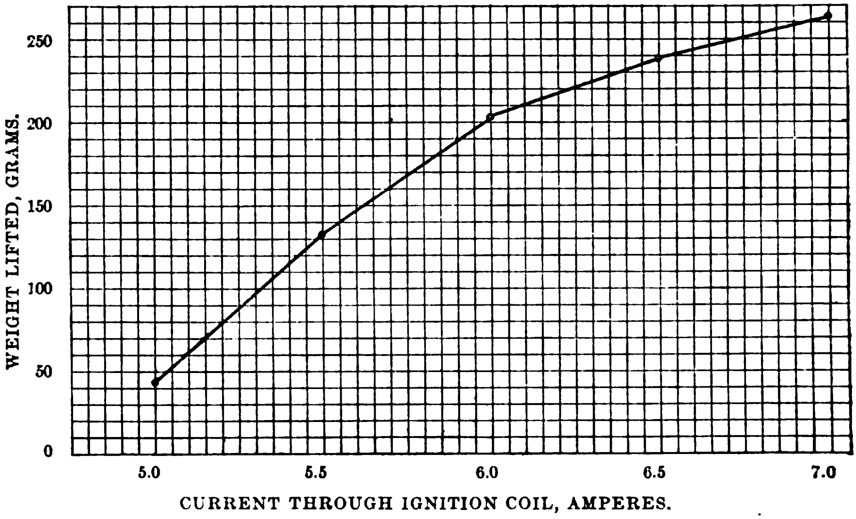

Figure 66.—Relative inflammability of coal No. 10825, Sheridan County, Wyo. Moisture, 13.49 per cent; volatile matter, 36.33 per cent; fixed carbon, 45.10 per cent; ash, 5.08 per cent; sulphur, 0.34 per cent.

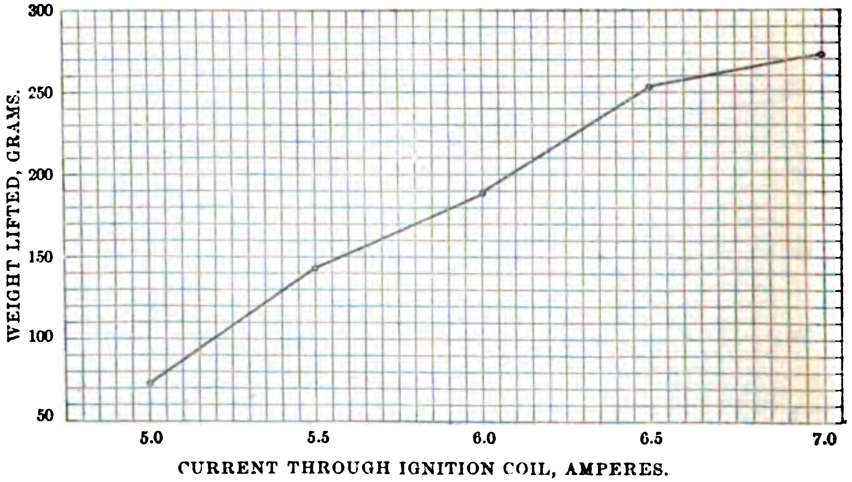

Figure 67.—Relative inflammability of coal No. 11048, Converse County, Wyo. Moisture, 16.08 per cent; volatile matter, 36.91 per cent; fixed carbon, 41.62 per cent; ash, 5.39 per cent; sulphur, 0.53 per cent.

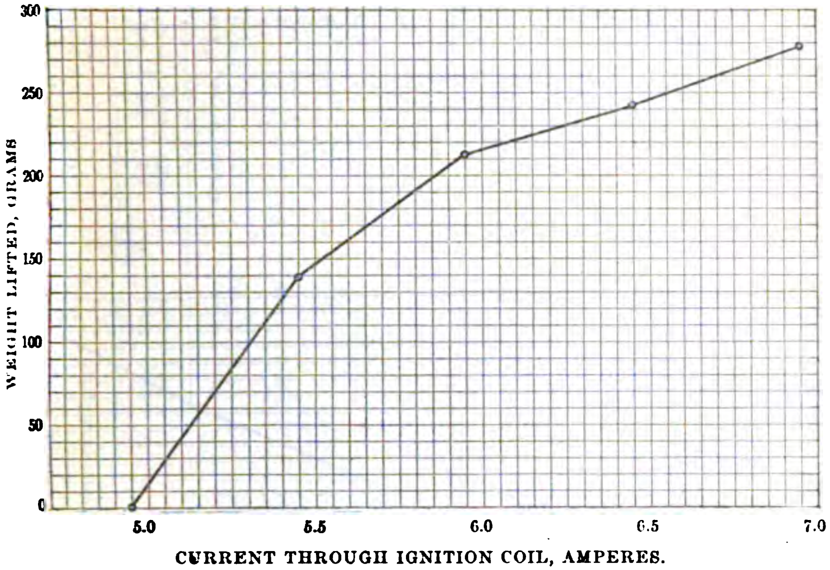

FIGURE 68.—Relative inflammability of coal No. 10822, Sheridan County, Wyo. Moisture, 13.94 per cent; volatile matter, 35.12 per cent; fixed carbon, 45.44 per cent; ash, 5.50 per cent; sulphur, 0.56 per cent.

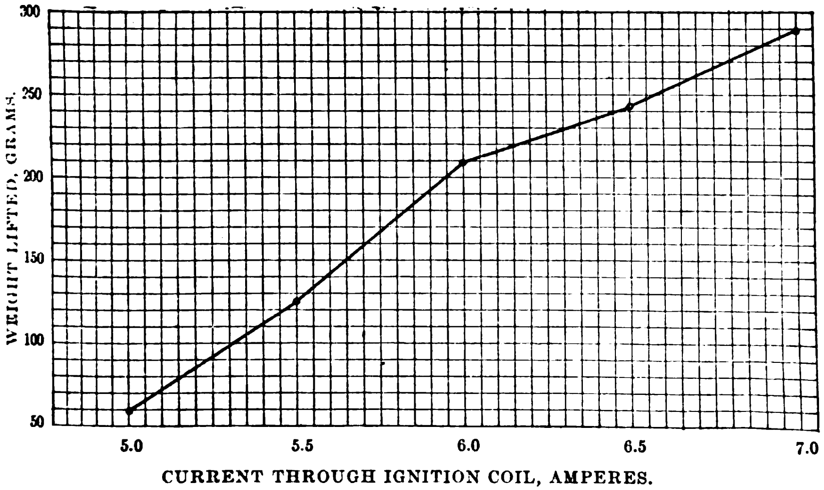

FIGURE 69.—Relative inflammability of coal No. 12006, Sheridan County, Wyo. Moisture, 14.90 per cent; volatile matter, 37.28 per cent; fixed carbon, 43.82 per cent; ash, 4.00 per cent; sulphur, 0.43 per cent.

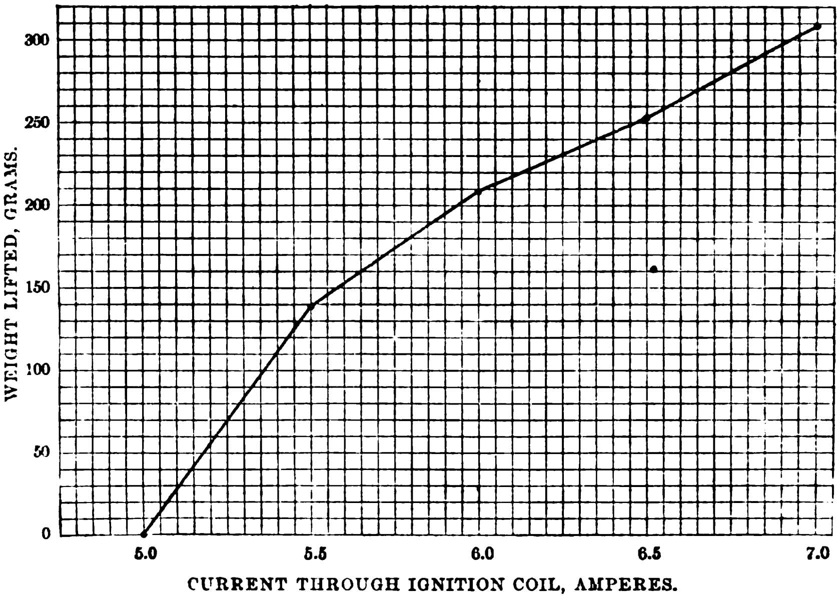

FIGURE 70.—Relative inflammability of coal No. 12008, Sheridan County, Wyo. Moisture, 14.97 per cent; volatile matter, 35.24 per cent; fixed carbon, 46.22 per cent; ash, 3.57 per cent; sulphur, 0.41 per cent.

TABLE 8.—*Dusts of group 2, road dusts.*

Laboratory number and description.	Chemical analysis (air-dried sample).							Inflammability.[a]	Weight lifted at different current strengths.				
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Oxygen.	Nitrogen.		5.0 amp.	5.5 amp.	6.0 amp.	6.5 amp.	7.0 amp.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
12024. Colorado, Las Animas County; Primero; Primero mine; Primero bed; bituminous coal (coked).	0.91	16.73	59.13	23.23	0.66	5.78	1.54	1	....	....	....	3	5
11936. Colorado, Las Animas County; Cokedale; Cokedale mine; bituminous coal.	1.11	20.44	38.99	39.46	.43	6.61	.86	2	....	3	8	18	60
11678. Ohio; bituminous coal	2.22	22.21	36.79	38.78	1.29	....	....	3	....	13	18	43	73
11136. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	2.02	14.85	21.35	61.78	.29	....	....	4	....	3	8	68	83
11931. Colorado, Las Animas County; Forbes; Forbes No. 9 mine; bituminous coal.	1.58	24.72	38.86	34.84	.52	....	....	5	....	8	23	123	123
11140. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	1.11	27.31	46.08	25.50	.62	....	....	6	....	8	18	73	128
11142. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	1.19	26.55	43.34	28.92	.58	....	....	7	....	10	23	78	128
11141. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	.99	25.61	44.69	28.71	.49	....	....	8	....	8	18	103	128
11434. Colorado, Las Animas County; Delagua; Delagua mine; bituminous coal.	1.33	27.61	37.42	33.64	.64	....	....	9	....	5	8	43	130
11571. Oklahoma, Pittsburg County; 2 miles east of McAlester; Busby No. 5 mine; McAlester bed; bituminous coal.	1.52	25.78	42.43	30.27	.50	....	....	10	....	8	13	98	133
11139. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	1.15	26.68	47.22	24.95	.53	....	....	11	....	5	23	93	143
11438. Colorado, Las Animas County; Delagua; Delagua mine; bituminous coal.	1.43	27.87	36.39	34.31	.82	....	....	12	....	3	8	38	145

[a] The relative inflammability of the dusts is based on the results of the tests in which the greatest current strength was on the wire (see p. 8), and the dust least inflammable with that current strength under the conditions of the tests is ranked 1 in this table

TABLE 3.—*Dusts of group 2, road dusts*—Continued.

Laboratory number and description.	Chemical analysis (air-dried sample).							Inflammability.	Weight lifted at different current weights.				
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Oxygen.	Nitrogen.		5.0 amp.	5.5 amp.	6.0 amp.	6.5 amp.	7.0 amp.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
11137. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	0.91	20.80	35.11	43.18	0.40	....	....	13	....	13	18	123	143
11133. Pennsylvania, Allegheny County; Creighton; Hite mine; Freeport bed; bituminous (cannel) coal.	.72	26.28	36.59	36.41	1.59	....	....	14	....	18	43	158	148
11138. Colorado, Las Animas County; Starkville; Starkville mine; Engleville-Starkville bed; bituminous coal.	1.02	29.69	51.47	17.82	.61	....	....	15	....	18	48	78	153
11439. Colorado, Las Animas County; Delagua; Delagua mine; bituminous coal.	1.25	30.40	38.12	30.23	.75	....	....	16	....	3	13	33	163
11593. Oklahoma, Pittsburg County; 2 miles east of Alderson; Alderson mine; McAlester bed; bituminous charred dust.	1.70	31.65	54.20	12.45	.53	....	....	17	....	10	18	133	168
11570. Oklahoma, Pittsburg County; 2 miles east of McAlester; Busby No. 5 mine; McAlester bed; bituminous coal.	1.45	29.05	51.20	18.30	.65	....	....	18	....	10	23	158	168
12002. Wyoming, Sheridan County; Monarch; Monarch mine; Monarch bed; subbituminous coal.	10.54	34.53	43.58	11.35	.90	....	....	19	5	38	168	238	263
12003. Wyoming, Sheridan County; Monarch; Monarch mine; Monarch bed; subbituminous coal.	8.17	35.18	46.45	10.20	1.27	....	....	20	23	128	165	228	283
12007. Wyoming, Sheridan County; Monarch; Monarch mine; Monarch bed; subbituminous coal.	8.95	37.62	45.96	7.47	1.07	....	....	21	23	128	203	253	300

TABLE 4.—*Dusts of group 3, mixtures of coal dust with shale or with calcium chloride.*

Laboratory number and description.	Chemical analysis (air-dried coal).							Inflammability.[a]	Weight lifted at different current strengths.					For curve see fig. No.—
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Oxygen.	Nitrogen.		5.0 amperes.	5.5 amperes.	6.0 amperes.	6.5 amperes.	7.0 amperes.	
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
11184. Kansas, Crawford County; Fuller; No. 2 shaft	1.50	34.71	54.37	9.42	5.12	5.60	1.28	1	15	45	110	195	215	71
11184+10 per cent shale									11	40	90	170	185	
11184+20 per cent shale									10	35	75	140	160	
11184+30 per cent shale									9	30	55	100	140	
11184+40 per cent shale									8	20	30	80	120	
11184+50 per cent shale									8	15	20	65	95	
11188. Missouri, Barton County, 2 miles northwest of Minden Mines, No. 7 shaft.	1.64	32.37	53.99	12.00	5.22	6.16	1.14	2	13	73	133	215	233	72
11188+10 per cent calcium carbonate										43	98	195	223	
11188+20 per cent calcium carbonate										23	63	118	183	
11188+30 per cent calcium carbonate										20	33	88	173	
11188+40 per cent calcium carbonate										13	30	80	155	
11188+50 per cent calcium carbonate										13	23	65	108	
10736. Virginia, Russell County, 2 miles north of Dante; No. 2 mine; Upper Banner bed.	.98	35.60	57.54	5.88	.60	5.25	1.46	3	15	75	140	205	240	73
10736+10 per cent shale									12	65	130	195	235	
10736+20 per cent shale									11	60	110	185	225	
10736+30 per cent shale									10	30	80	155	190	
10736+40 per cent shale									9	15	30	95	140	
10736+50 per cent shale									8	15	25	50	90	
10909. Utah, Carbon County; Hiawatha; Hiawatha No. 2 mine; Hiawatha (?) bed.	3.33	41.79	47.76	7.12	.57	13.89	1.42	4	50	100	175	245	275	74
10909+10 per cent shale									50	90	170	240	265	
10900+20 per cent shale									45	75	155	230	255	
10909+30 per cent shale									30	60	120	195	220	
10909+40 per cent shale									20	40	90	155	180	
10909+50 per cent shale									15	30	60	120	155	
10825. Wyoming, Sheridan County; Acme; Acme No. 1 mine; "Carney vein."	13.49	36.33	45.10	5.08	.34	27.93	1.22	5	45	105	200	250	280	75
10825+10 per cent shale									40	95	180	235	270	
10825+20 per cent shale									40	95	170	220	245	
10825+30 per cent shale									35	95	145	180	200	
10825+40 per cent shale									25	70	100	135	155	
10825+50 per cent shale									15	30	60	100	125	

[a] The relative inflammability of the dusts is based on the results of the tests in which the greatest current strength was on the wire (see p. 8), and the dust least inflammable with that current strength under the conditions of the tests is ranked 1 in this table.

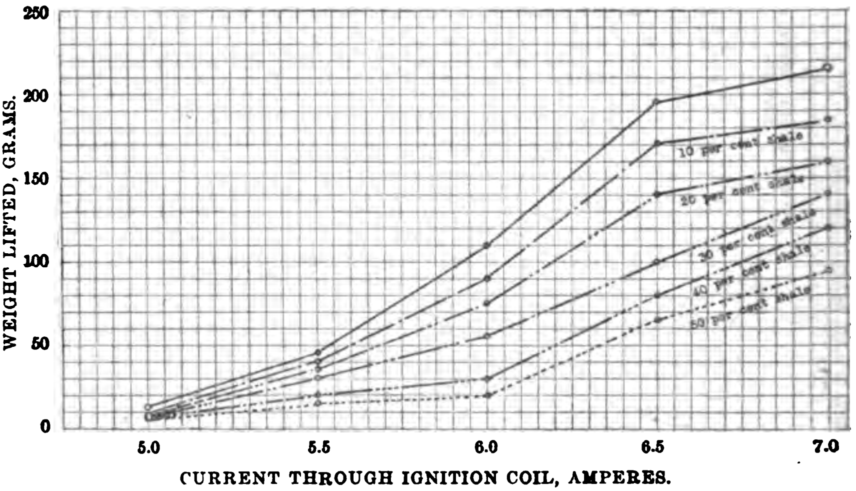

FIGURE 71.—Relative inflammability of coal No. 11184, Crawford County, Kans., and of mixtures of coal No. 11184 with shale. Moisture, 1.50 per cent; volatile matter, 34.71 per cent; fixed carbon, 54.37 per cent; ash, 9.42 per cent; sulphur, 5.12 per cent.

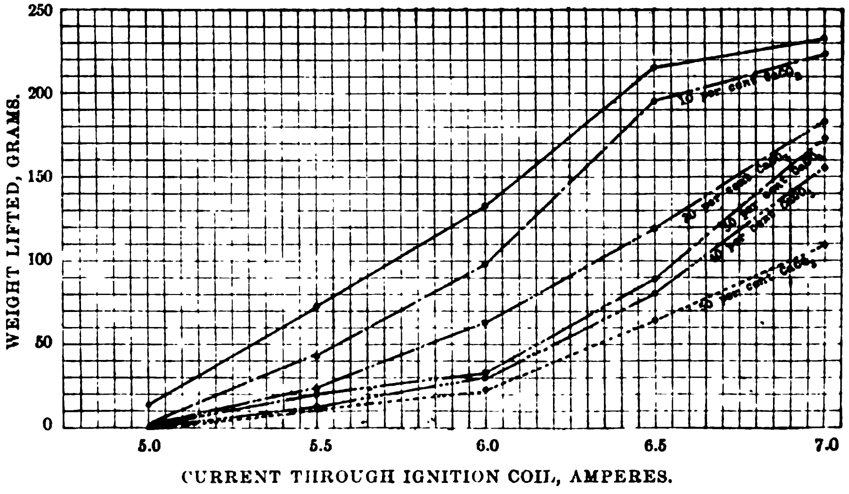

FIGURE 72.—Relative inflammability of coal No. 11188, Barton County, Mo., and of mixtures of coal No. 11188 with calcium carbonate. Moisture, 1.64 per cent; volatile matter, 32.37 per cent; fixed carbon, 53.99 per cent; ash, 12 per cent; sulphur, 5.22 per cent.

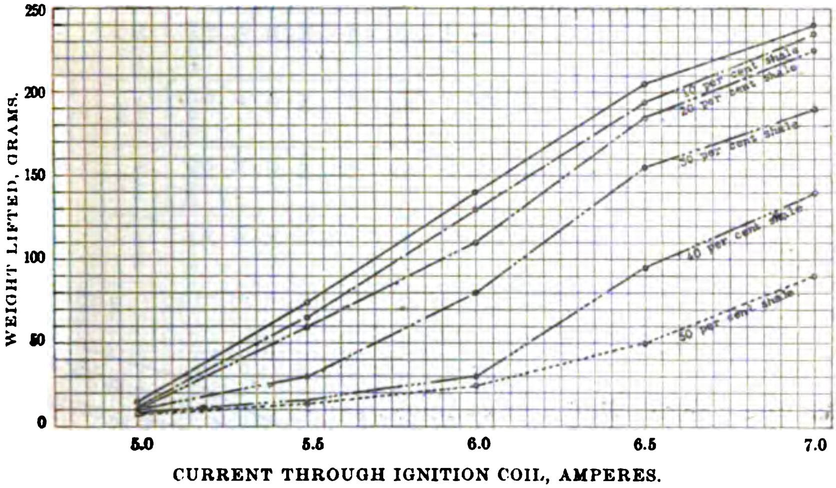

FIGURE 73.—Relative inflammability of coal No. 10736, Russell County, Va., and of mixtures of coal No. 10736 with shale. Moisture, 0.98 per cent; volatile matter, 35.60 per cent; fixed carbon, 57.54 per cent; ash, 5.88 per cent; sulphur, 0.60 per cent.

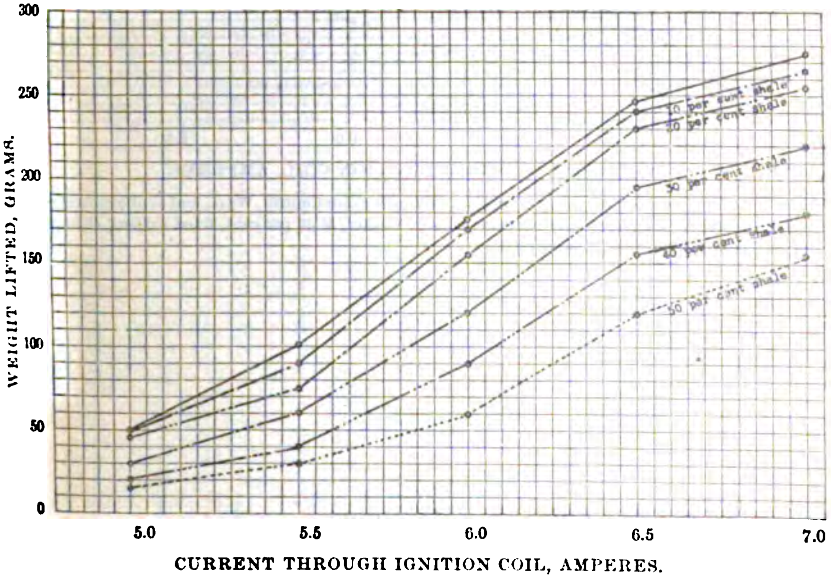

FIGURE 74.—Relative inflammability of coal No. 10909, Carbon County, Utah, and of mixtures of coal No. 10909 with shale. Moisture, 3.33 per cent; volatile matter, 41.79 per cent; fixed carbon, 47.76 per cent; ash, 7.12 per cent; sulphur, 0.57 per cent.

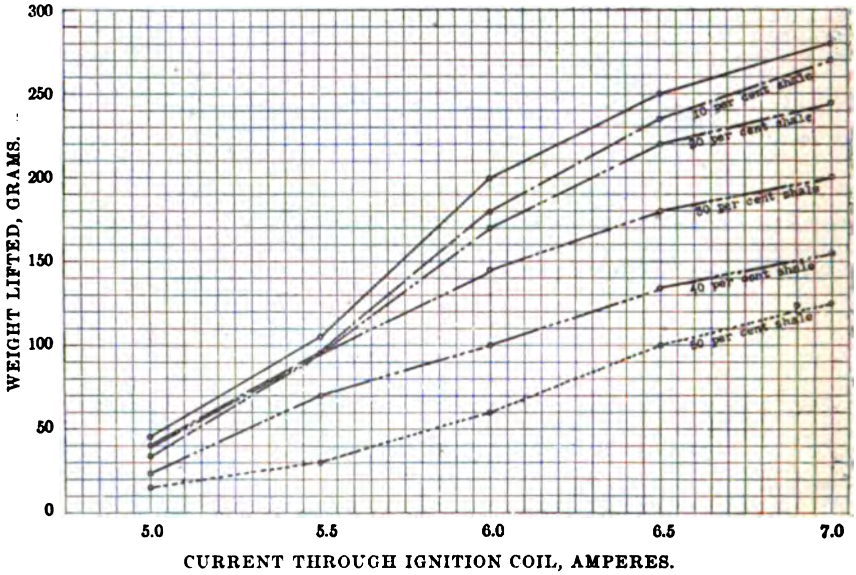

FIGURE 75.—Relative inflammability of coal No. 10825, Sheridan County, Wyo., and of mixtures of coal No. 10825 with shale. Moisture, 13.49 per cent; volatile matter, 36.33 per cent; fixed carbon, 45.10 per cent; ash, 5.08 per cent; sulphur, 0.34 per cent.

TABLE 5.—*Dusts of group 4, inflammable dusts other than coal dust.*

Laboratory number and description.	Chemical analysis (air-dried coal).							Inflammability.[a]	Weight lifted at different current strengths.					For curve see fig. No. —
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Oxygen.	Nitrogen.		5.0 amp.	5.5 amp.	6.0 amp.	6.5 amp.	7.0 amp.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	
11190. Flour	11.09	63.58	24.90	0.43	....	....	....	1	98	118	148	158	188	76
11689. Pine dust	4.38	71.92	16.02	7.68	....	....	....	2	13	18	43	178	218	77
11688. Oak dust	3.22	77.05	16.56	3.17	....	....	....	3	140	143	183	228	238	78
11386. Asphalt; Oklahoma; Pushmataha County; Jumbo; Jumbo mine.	.29	44.67	48.07	6.97	1.60	1.80	1.45	4	105	180	218	235	243	79
11388. Asphalt; Oklahoma; Pushmataha County; Jumbo; Jumbo mine.	.21	43.98	49.19	6.62	1.63	1.85	1.41	5	75	140	220	235	243	80
11387. Asphalt; Oklahoma; Pushmataha County; Jumbo; Jumbo mine.	.34	44.50	48.37	6.79	1.61	1.56	1.44	6	125	178	228	238	243	81
11189. Starch	14.58	70.21	14.87	.34	....	....	....	7	48	188	228	243	248	82
11389. Asphalt; Oklahoma; Pushmataha County; Jumbo; Jumbo mine.	.24	43.36	50.70	5.70	1.62	2.26	1.39	8	125	170	233	253	258	83
13331. Sugar	.00	95.15	4.85	.00	....	....	....	9	268	288	293	298	300	84
11690. Mahogany dust	5.55	72.71	19.91	1.83	....	....	....	10	138	160	193	288	308	85
13332. Lycopodium	2.04	87.39	8.98	1.59	.11	....	....	11	400	435	520	530	540	86

[a] The relative inflammability of the dusts is based on the results of the tests in which the greatest current strength was on the wire (see p. 8), and the dust least inflammable with that current strength under the conditions of the tests is ranked 1 in this table.

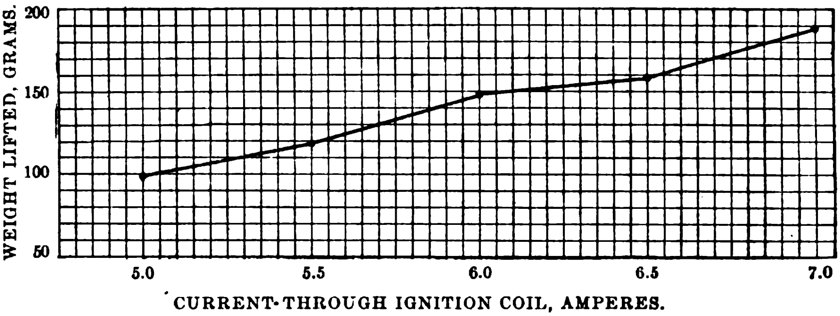

FIGURE 76.—Relative inflammability of flour, No. 11190. Moisture, 11.09 per cent; volatile matter, 63.58 per cent; fixed carbon, 24.90 per cent; ash, 0.43 per cent.

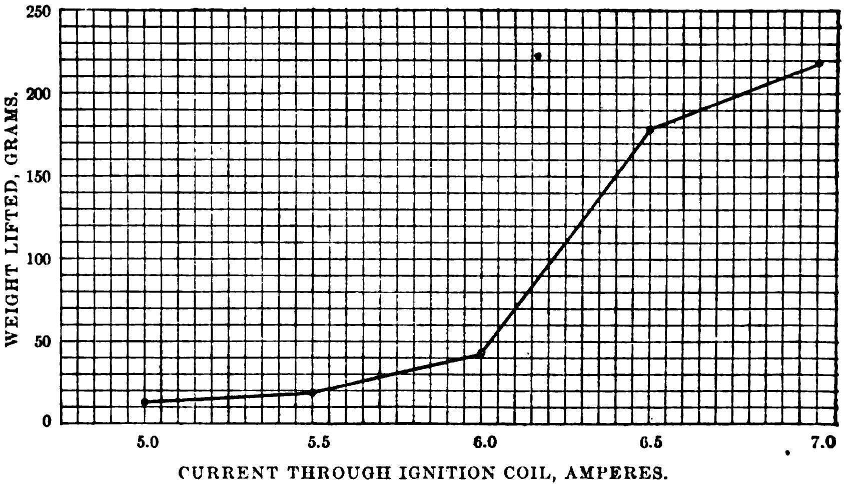

FIGURE 77.—Relative inflammability of pine dust, No. 11689. Moisture, 4.38 per cent; volatile matter, 71.92 per cent; fixed carbon, 16.02 per cent; ash, 7.68 per cent.

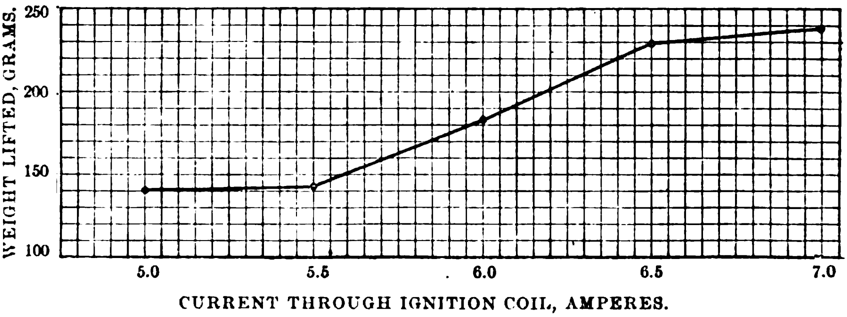

FIGURE 78.—Relative inflammability of oak dust, No. 11688. Moisture, 3.22 per cent; volatile matter, 77.05 per cent; fixed carbon, 16.56 per cent; ash, 3.17 per cent.

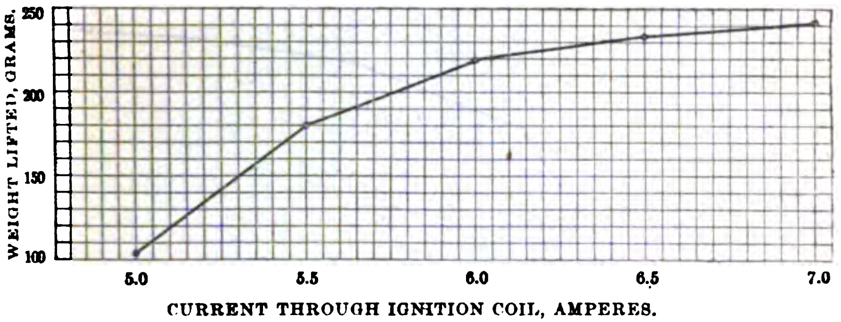

FIGURE 79.—Relative inflammability of asphalt No. 11386, Pushmataha County, Okla. Moisture, 0.29 per cent; volatile matter, 44.67 per cent; fixed carbon, 48.07 per cent; ash, 6.97 per cent; sulphur, 1.60 per cent.

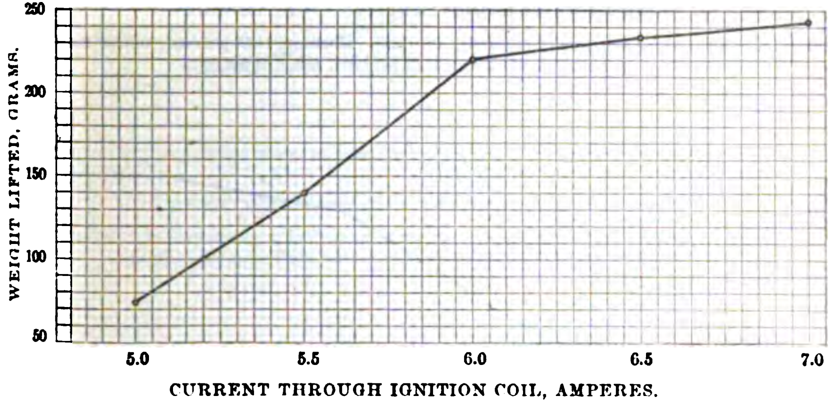

FIGURE 80.—Relative inflammability of asphalt No. 11388, Pushmataha County, Okla. Moisture, 0.21 per cent; volatile matter, 43.98 per cent; fixed carbon, 49.19 per cent; ash, 6.62 per cent; sulphur, 1.63 per cent.

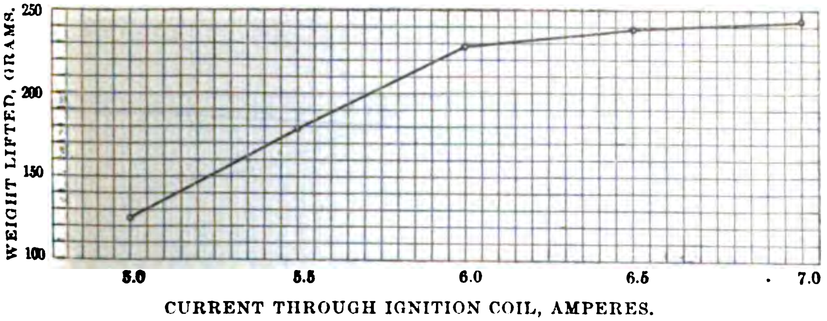

FIGURE 81.—Relative inflammability of asphalt No. 11387, Pushmataha County, Okla. Moisture, 0.34 per cent; volatile matter, 44.50 per cent; fixed carbon, 48.37 per cent; ash, 6.79 per cent; sulphur, 1.61 per cent.

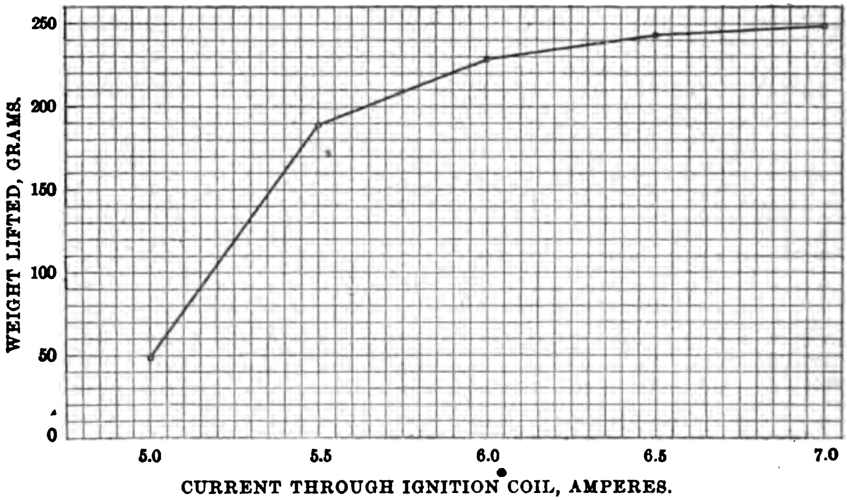

FIGURE 82.—Relative inflammability of starch, No. 11189. Moisture, 14.58 per cent; volatile matter, 70.21 per cent; fixed carbon, 14.87 per cent; ash, 0.34 per cent.

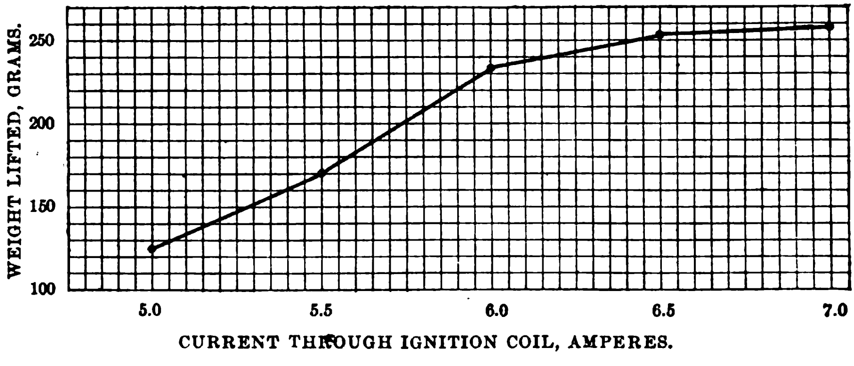

FIGURE 83.—Relative inflammability of asphalt No. 11389, Pushmataha County, Okla. Moisture, 0.24 per cent; volatile matter, 43.36 per cent; fixed carbon, 50.70 per cent; ash, 5.70 per cent; sulphur, 1.62 per cent.

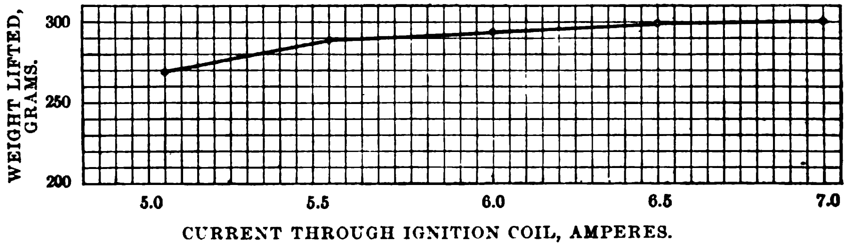

FIGURE 84.—Relative inflammability of sugar, No. 13331. Moisture, 0.00 per cent; volatile matter, 95.15 per cent; fixed carbon, 4.85 per cent; ash, 0.00 per cent.

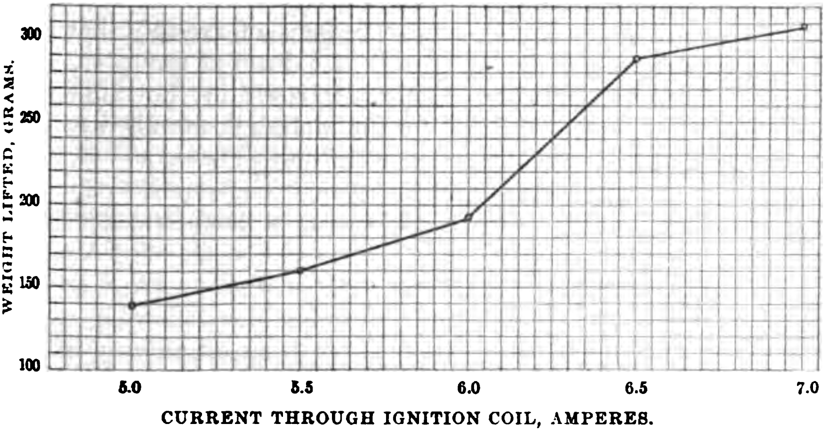

FIGURE 85.—Relative inflammability of mahogany dust, No. 11690. Moisture, 5.55 per cent; volatile matter, 72.71 per cent; fixed carbon, 19.91 per cent; ash, 1.83 per cent.

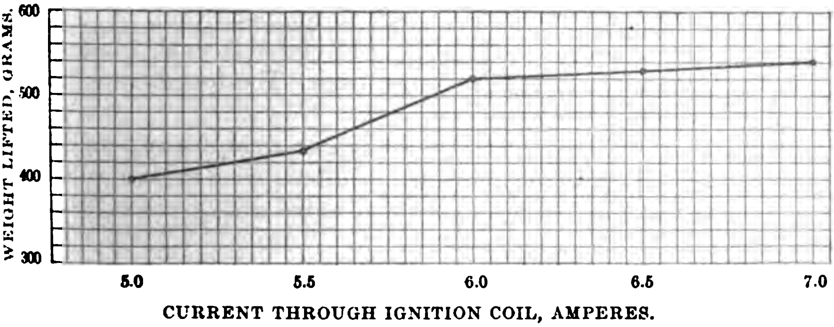

FIGURE 86.—Relative inflammability of lycopodium, No. 13332. Moisture, 2.04 per cent; volatile matter, 87.39 per cent; fixed carbon, 8.98 per cent; ash, 1.59 per cent; sulphur, 0.11 per cent.

DISCUSSION OF RESULTS.

In any statement, such as the preceding tables, of the relative inflammability of dusts, ranking of the different samples depends on conditions. In the tables and curves the samples are compared on the basis of the results obtained with the largest current used, namely, 7 amperes. The order of inflammability would have been different if the results obtained at a different current strength had been used, or if the tests had been made on a large scale.

As stated above, the inflammability curves for the various coal dusts are in general of two types, and the dusts of group 1 have been divided on this basis. The curves for the dusts of group 1A ascend continuously throughout their whole length within the range of the experiments, whereas the curves for the coals of group 1B rise rapidly at first and finally become parallel to the horizontal axis. Group 1A includes 50 semibituminous and bituminous coals and 8 subbituminous coals and lignites. Group 1B consists of 9 subbituminous coals and 1 lignite.

Of the 8 subbituminous coals and lignites of group 1A, 4 are to be excluded in comparing inflammability for the following reasons: Coal sample No. 10900 (fig. 3) was taken from an outcrop and was probably weathered, as is indicated by its containing, on a moisture and ash-free basis, 27.47 per cent of oxygen and having a heating value of 5,867 calories as against oxygen, 24.42 per cent and calories 6,455 in the case of sample No. 10899 (fig. 62) taken from the same locality and having a similar proximate analysis. Coal sample No. 11059 (fig. 17) was from an open bank mined for local use and may have been weathered. Coal sample No. 10997 (fig. 32) was from a prospect; and coal sample No. 11058 (fig. 57) was from an abandoned mine.

Attention is called to the extremely high moisture content of sample No. 11361 (fig. 6), the very high ash content of sample No. 10741 (fig. 25), and the high moisture and ash content of sample No. 10732 (fig. 11).

Neither should sample No. 11382, bituminous coal, of group 1A (fig. 31) and sample No. 11048, subbituminous coal, of group 1B (fig. 67) be considered in this connection. The former was from an outcrop, the latter from an open bank.

In the light of the above facts, though no rigid distinction between the coals can be drawn on the basis of difference in form of inflammability curve, still the general relations noted above are hardly to be considered as purely accidental.

Group 3 contains samples of coal dust to which 10, 20, 30, 40, and 50 per cent of finely ground shale or of calcium carbonate was added. These were included in order to measure the effectiveness of this proposed means of diminishing the inflammability of coal dust. In all the experiments with these artificially prepared dusts, such an amount of each was always taken as contained the same quantity of the pure coal dust that had been used in all the other experiments, so that the same amount of coal dust was in suspension in all cases. The effect of the shale dust in limiting the inflammation is seen with each successive addition, the effect being decidedly marked with the 50 per cent mixture but not sufficient to render the sample noninflammable.

RESULTS OF TESTS WITH EUROPEAN COALS.

In figures 87–94 are given curves of inflammability for coals from France, England, Germany, and Austria. The authors are indebted to G. S. Rice, chief mining engineer, for the samples which he collected personally. The curves are presented without discussion, in the belief that they may prove of interest in connection with the curves previously given.

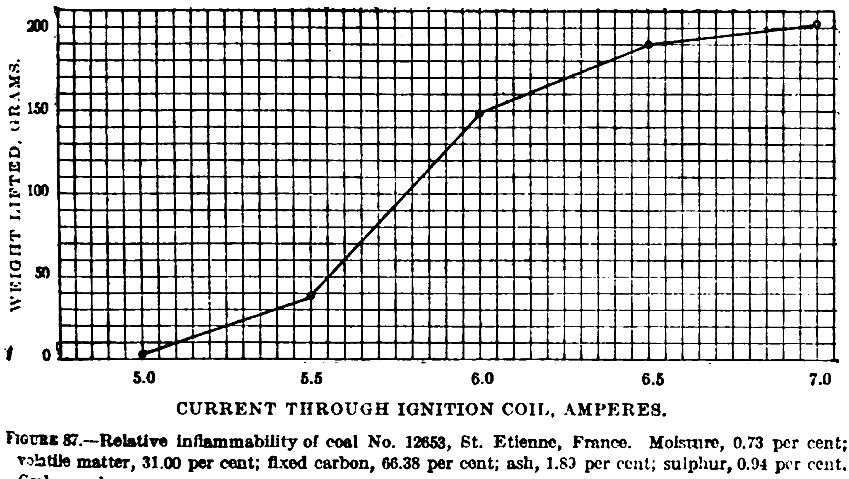

FIGURE 87.—Relative inflammability of coal No. 12653, St. Etienne, France. Moisture, 0.73 per cent; volatile matter, 31.00 per cent; fixed carbon, 66.38 per cent; ash, 1.89 per cent; sulphur, 0.94 per cent. Grab sample.

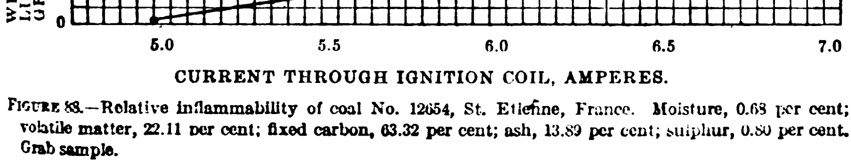

FIGURE 88.—Relative inflammability of coal No. 12654, St. Etienne, France. Moisture, 0.68 per cent; volatile matter, 22.11 per cent; fixed carbon, 63.32 per cent; ash, 13.89 per cent; sulphur, 0.80 per cent. Grab sample.

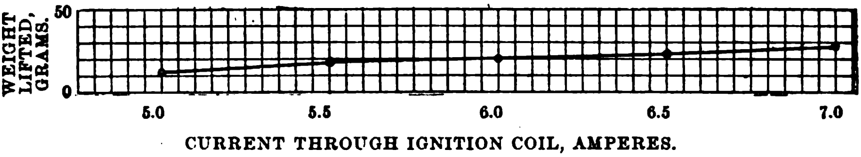

FIGURE 89.—Relative inflammability of coal No. 12655, Ferndale, England. Moisture, 0.78 per cent; volatile matter, 15.78 per cent; fixed carbon, 81.95 per cent; ash, 1.49 per cent; sulphur, 0.59 per cent. Grab sample.

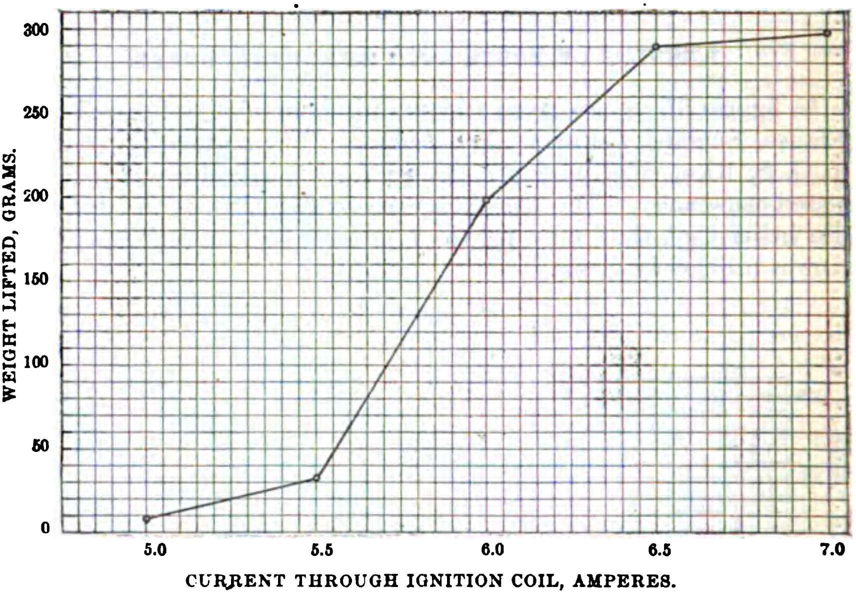

FIGURE 90.—Relative inflammability of coal No. 12656, Upper Silesia, Germany. Moisture, 6.70 per cent; volatile matter, 36.22 per cent; fixed carbon, 54.18 per cent; ash, 2.90 per cent; sulphur, 0.99 per cent. Grab sample.

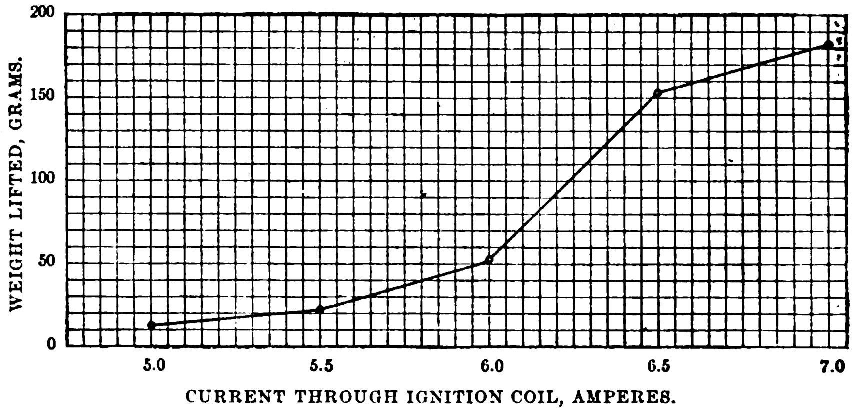

FIGURE 91.—Relative inflammability of coal No. 12657, Westphalia, Germany. Moisture, 1.56 per cent; volatile matter, 30.65 per cent; fixed carbon, 62.66 per cent; ash, 5.13 per cent; sulphur, 0.98 per cent. Grab sample.

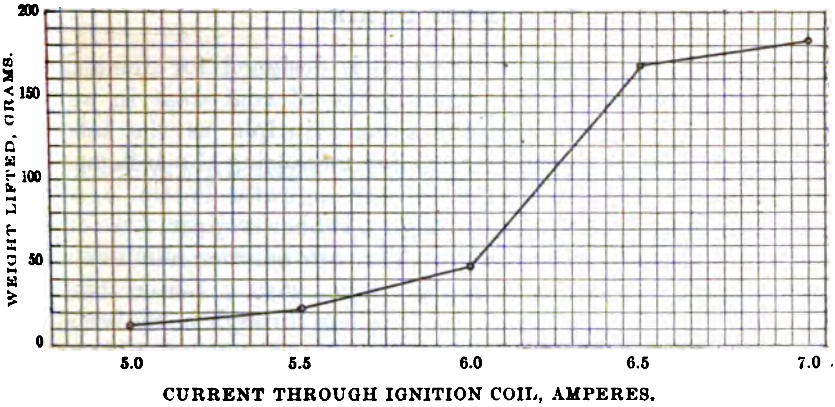

FIGURE 92.—Relative inflammability of coal No. 12658, Westphalia, Germany. Moisture, 1.49 per cent; volatile matter, 33.89 per cent; fixed carbon, 60.04 per cent; ash, 4.58 per cent; sulphur, 1.56 per cent. Grab sample.

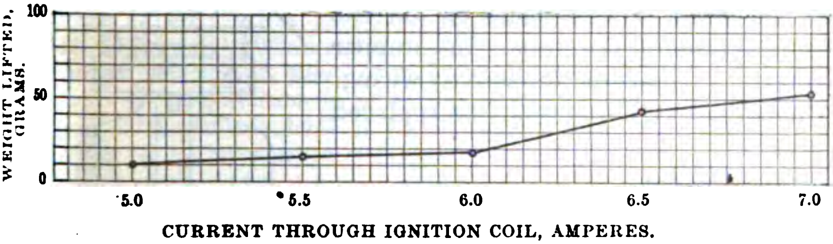

FIGURE 93.—Relative inflammability of coal No. 12659, Westphalia, Germany. Moisture, 0.61 per cent; volatile matter, 18.96 per cent; fixed carbon, 71.59 per cent; ash, 8.85 per cent; sulphur, 1.95 per cent. Grab sample.

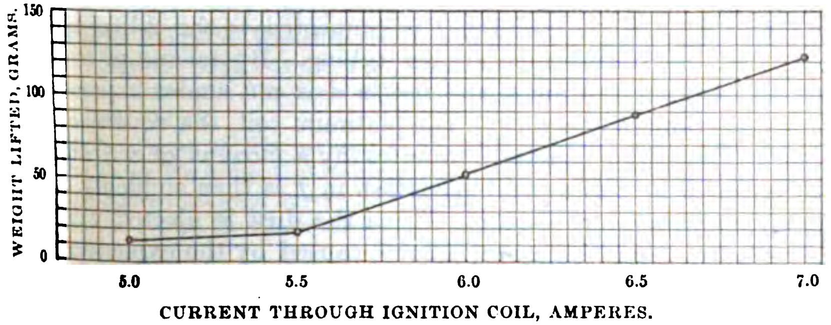

FIGURE 94.—Relative inflammability of coal No. 12660, Segen-Gottes, Austria. Moisture, 0.99 per cent; volatile matter, 20.98 per cent; fixed carbon, 65.17 per cent; ash, 12.86 per cent; sulphur, 3.26 per cent. Standard dust used in Rossitz gallery.

LABORATORY DEMONSTRATION OF INFLAMMABILITY OF COAL DUST IN AIR.

The apparatus shown in figure 95 is designed for demonstrating on a laboratory scale the explosibility of coal dust in air. The apparatus is assembled on the same principle as the laboratory apparatus already shown (fig. 2) for measuring the inflammability of coal dust. It consists of a 14-liter aspirator bottle, *a*, of thick glass, in which is suspended through a rubber stopper, *l*, a coil of 1.5 meters of No. 26 platinum wire. Through another hole in *l* connection is made, by means of a glass tube, with a 1-liter thin-walled Florence flask, *b*, the glass tube passing through a rubber stopper secured in the mouth of the flask by wire. The stopper *l* is held gas tight in *a* by means of a steel piece bolted to a split wooden collar, *c*, clamped around the neck of *a*. Through the tubulure *r*, at the bottom of *a*, is inserted a one-hole rubber stopper carrying a copper funnel, *f*, which is directed upward inside the bottle beneath the coil and is covered with a piece of wire gauze to aid the dissemination of the dust. The stopper carrying *f* is secured in place by wiring. About 5 grams of fine coal dust is placed in *f*, and the projecting end of *f* is connected to the 2-liter bottle *d* by means of thick-walled rubber tubing. By means of the compression bulb *h* the air in the bottle *d* is put under a pressure of about 450 mm. of mercury. The platinum coil, the source of ignition, is heated for about 10 minutes by a current of 6.5 amperes, when the air in *a* is warm. The dust in *f* is then suddenly ejected by opening the pinch cock *g*. When the dust is ejected, *a* is filled with flame, and a loud report follows, caused by the explosion of the flask.

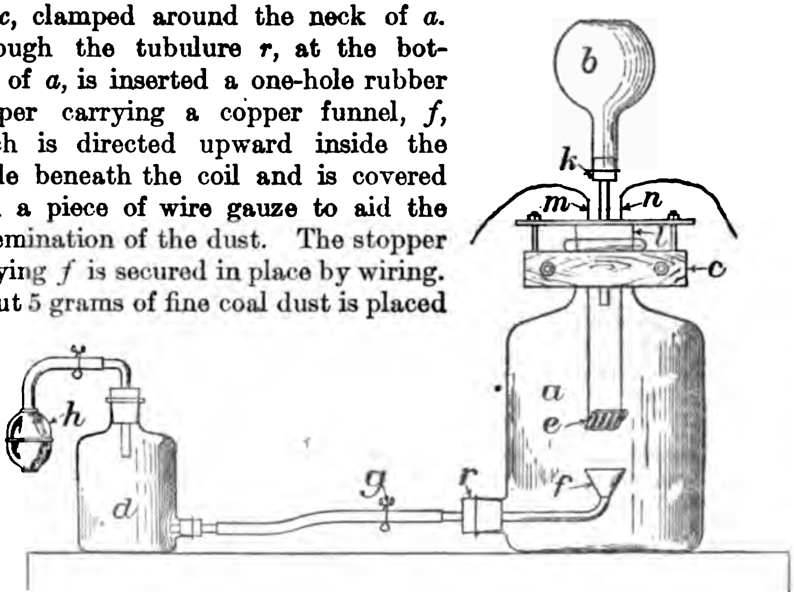

FIGURE 95.—Apparatus for demonstrating the inflammability of coal dust.

The experiment is performed with safety only when the bottle *a* and flask *b* are inclosed in a heavy box with a thick plate-glass front, otherwise injury may be caused by the projected pieces of glass.

PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls., 4 figs.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls., 5 figs.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosability of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine by G. S. Rice. 1912. 75 pp., 7 pls., 4 figs.

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TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl., 5 figs.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions; report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

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TECHNICAL PAPER 42. The prevention of waste of oil and gas from flowing wells in California, with a description of special methods used by J. A. Pollard, by Ralph Arnold and V. R. Garfias. 1913. 15 pp., 2 pls., 4 figs.

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MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

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Bulletin 51

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE ANALYSIS OF BLACK POWDER AND DYNAMITE

BY

WALTER O. SNELLING AND C. G. STORM

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

First edition. March, 1913.

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THE ANALYSIS OF BLACK POWDER AND DYNAMITE.

By WALTER O. SNELLING and C. G. STORM.

INTRODUCTION.

Although descriptions of the methods of analysis of explosives are to be found in many books on explosives, and in works on engineering chemistry or chemical analysis, most of these descriptions are incomplete and lacking in details. The methods of analysis employed in the laboratories of most explosives factories are frequently treated as trade secrets, and very little information is published from such laboratories.

This bulletin outlines the methods of analysis that are used by the Bureau of Mines in the examination of certain classes of explosives. The present form of most of these methods has been worked out in the bureau's explosives laboratory. The methods employed by Prof. C. E. Munroe were taken as a basis, and were elaborated to meet the demands incident to the treatment of complicated mixtures and to the development of the explosives art. A subsequent bulletin will discuss the methods of analysis of "permissible" explosives, many of the latter being of decidedly complicated character and requiring special treatment. This bulletin presents the methods of analysis of "ordinary" dynamite, and the ammonia, gelatin, low-freezing, and granular dynamites, and the common grades of black gunpowder and black blasting powder. The bulletin is published by the bureau for the information of all persons interested in explosives and their safe and efficient use in mining work.

As the term "ordinary" dynamite, though much used, has no conventional meaning, and may be used to cover a wide variety of compositions of matter, it may be noted that the standard dynamite used at the Pittsburgh testing station is a good example of the "ordinary" dynamite known in this country. This testing station dynamite has the following composition:

Composition of Pittsburgh testing station dynamite.

	Per cent.
Nitroglycerin	40
Sodium nitrate	44
Wood pulp	15
Calcium carbonate	1

As most permissible explosives contain only the constituents found generally in the various types of ordinary dynamite, the chemist will usually find it possible to analyze such explosives either wholly or partly by following the general methods of analysis here given for the type of explosive that seems most closely related to the one under examination. The methods of extraction with ether, with water, etc., here outlined are general methods which are applied with equal success to all classes of explosives, and therefore by the use of these general methods, following a thorough qualitative examination, little difficulty should be met except with those classes of permissible explosives that contain large amounts of salts holding water of crystallization, such as alum and magnesium sulphate, or those containing an unusual number of uncommon constituents. Even with such explosives, however, if the information desired is principally in regard to the percentages of explosive ingredients (nitroglycerin, ammonium nitrate, etc.), the methods outlined in this bulletin may be satisfactorily followed.

DYNAMITE.

"Ordinary" dynamite consists essentially of nitroglycerin absorbed in some porous material. Owing to its physical condition and its extreme sensitiveness to shock, liquid nitroglycerin is not suitable for use as an explosive in mining and quarrying, but when nitroglycerin is absorbed in a porous material a more or less plastic mass is obtained which is far less sensitive to shock than liquid nitroglycerin, although, when properly fired by means of a detonator, it retains most of the explosive properties of nitroglycerin. Among the many substances that have been used as absorbents for nitroglycerin are sawdust, wood pulp, ground mica, and infusorial earth (kieselguhr), or mixtures of these substances with alkaline nitrates and other substances.

It is usual to classify absorbents for nitroglycerin as active and inactive. Pulverized gunpowder, for example, or mixtures of wood pulp with sodium nitrate or other oxidizing agents, represent "active" absorbents, whereas mica, kieselguhr and similar materials, which play no part in the explosive reactions and which are employed merely to absorb or retain the liquid nitroglycerin, form the so-called "inactive" absorbents.

The type of dynamite most generally used to-day consists of nitroglycerin absorbed in a mixture of wood pulp and sodium nitrate, and to this mixture is usually added a small amount of some antacid such as calcium carbonate, magnesium carbonate, or zinc oxide. This antacid is added in the belief that it increases the stability of the resulting explosive by neutralizing such small amounts of free acid as may be produced by the decomposition of the nitroglycerin during long storage.

The analysis of dynamite is best carried out by first separating, with ether or some other appropriate solvent, the nitroglycerin from the dope in which it is absorbed. After the nitroglycerin has been thus removed, the soluble nitrate in the dope may be removed by dissolving in water; the antacid may then be dissolved in dilute acid, and the residue insoluble in ether, water, dilute acid, etc., may be directly determined by weight.

In its simplest form, therefore, the analysis of dynamite consists in the removal of the constituent materials, one by one, through the use of appropriate solvents. Dynamites of the most complicated composition may usually be analyzed in this way, through selective solution. In the present paper the methods of analyzing ordinary types of dynamite are discussed, and those that have been found best in an experience covering several thousand analyses are stated.

PHYSICAL EXAMINATION.

Upon receiving a sample of explosive for analysis it is desirable to record full information in regard to the size and weight of each cartridge, with a complete copy of any lettering that may appear on the wrapper. It is also advisable to record the nature of the outer wrapping paper (such as ordinary paper, parchmentized paper, or paper coated with paraffin), and whether the cartridge has been redipped; that is, placed in a paraffin bath after being filled. Whether a cartridge has been redipped can usually be determined by carefully opening the wrapper. If there is a greater thickness of paraffin near the edge where the sheet overlaps, or if the overlapping edge is attached to the adjacent portions of the paper by means of an adhering deposit of paraffin, it may be assumed that the cartridge has been redipped.

DETERMINATION OF GRAVIMETRIC DENSITY.

It is possible to determine approximately the gravimetric density or apparent specific gravity of a cartridge of explosive by measuring carefully the length and circumference of the cartridge, calculating from these figures the volume in cubic centimeters, and then dividing the weight in grams of the cartridge by this figure. However, experiments made at the bureau's explosives laboratory have shown that even with the most careful measurements the figures thus obtained are liable to be in error by as much as 10 to 20 per cent, a difference entirely too great to make the method permissible for exact work. With some redipped cartridges weighing in water has given satisfactory results, but cartridges seldom have a coating of paraffin so complete as to permit the use of this method. Accordingly a method was sought that would at all times give satisfactory results even with cartridges that had not been redipped.

The volume of the cartridge can be determined conveniently by using sand instead of water as the measuring material. A weighed glass cylinder about 30 cm. high and 5 cm. in inside diameter is filled with fine sand (preferably sea sand) that has been sifted through a 60-mesh sieve. A straight edge is drawn across the top of the cylinder, the level of the sand being left flush with the top edge, and the weight of the cylinder and contained sand is determined. From this weight the weight of the cylinder is subtracted and the result is the weight of the sand, which, divided by the weight of water required to fill the cylinder, gives the apparent specific gravity of the sand used. All the sand except enough to fill the cylinder to a depth of about 1 inch is now poured out, a weighed cartridge of the explosive is placed in the cylinder, and sand added until the cylinder is filled flush to the top as before, when it is struck with the straight edge and then the weight of cylinder and sand and cartridge is noted. From these figures the weight of sand displaced by the cartridge is found. This weight divided by the apparent specific gravity of the sand gives the volume of the cartridge. The weight of the cartridge divided by its volume gives its apparent specific gravity or gravimetric density. This determination leaves the cartridge in condition for use in sampling, if desired.

In making this determination care should be taken that the cylinder is filled each time in exactly the same manner, the sand being poured in slowly and not packed by jolting, shaking or otherwise. Repeated determinations of the weight of sand required to just fill the cylinder will prove that with proper care uniform results may be obtained; in practice this method has been found to be both rapid and exact.

TEST FOR LIABILITY OF EXUDATION.

To determine whether there is liability of leakage of nitroglycerin from cartridges containing this explosive, it is always advisable to make an exudation test, which indicates the amount of nitroglycerin that may be lost by the explosive tested under prescribed conditions. The tests most commonly used for this purpose are the 40° test, the pressure test, and the centrifugal test.

40° TEST FOR EXUDATION.

In the 40° test a cartridge of the explosive under examination is placed in a vertical position in an oven heated to 40° C. Some small perforations are made in the wrapper at the ends of the cartridge, and the cartridge is then placed on end on a small wire tripod in a small glass beaker or cylinder. The whole is then placed for six days in an oven maintained at a constant temperature of 40° C. At the end of this time an examination is made to see if any leakage of nitroglycerin in the form of drops has occurred. Such leakage may be taken as evidence that there is too much nitroglycerin in the explosive for the amount of absorbent material present, or that the dope used is deficient in absorbing capacity.

PRESSURE TEST FOR EXUDATION.

Before the centrifugal test was employed, it was customary to use a pressure test for exudation which consisted in exposing a sample of the dynamite to a definite pressure produced by a weight on a lever arm, and determining the amount of nitroglycerin thereby forced out of the dynamite. Many modifications of this test have been tried, in which cotton, blotting paper, or other absorbent material have been used to hold the nitroglycerin forced out from the explosive. The pressure test is unreliable and hence is not satisfactory in use. For example, by this test an explosive that contains a certain amount of a mixture of sawdust and wood pulp shows less exudation than one in which the same amount of absorbent is used in the form of wood pulp alone, a result that is clearly incorrect, since the absorbing power of wood pulp is much greater than that of sawdust. The reason for the more favorable result when the absorbent contains sawdust is that the particles of sawdust are packed together to form a cellular mass, which incloses the particles of wood pulp holding the nitroglycerin, thereby in a great measure protecting them from pressure.

CENTRIFUGAL TEST FOR EXUDATION.

The use of centrifugal force as a means of measuring the completeness with which nitroglycerin is absorbed in an explosive was some years ago suggested to Col. B. W. Dunn, chief inspector of the bureau for the safe transportation of explosives, by T. J. Wrampelmeier, an inspector in that bureau, and a device for testing the value of this method was made use of by C. P. Beistle,[a] chief chemist of that bureau. The method employed was to place the explosive, together with a perforated disk of vulcanite and an absorbent material such as cotton, within a glass tube, the tube being then placed in a centrifuge. The increase in weight of the cotton after rotation was taken as a measure of the amount of nitroglycerin lost by the explosive during the process. This apparatus gives much more satisfactory results than the former methods of testing by pressure alone, but owing to the fact that the cotton becomes compressed during rotation, thus changing the position of the vulcanite disk, the apparatus at times gives discordant results, and the figures from tests of any two explosives are not proportional to the relative tendency toward leakage of nitroglycerin under normal conditions.

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[a] Report of chief inspector of the bureau for the safe transportation of explosives, February, 1909.

One of the authors designed a centrifuge attachment which is now being used with reliable results by the Bureau of Mines. This apparatus is shown in Plate I, *A*. Two samples of the explosive are placed in ordinary porcelain Gooch crucibles, without mat, the crucibles being held above two other nonperforated crucibles in the manner shown. A small amount of cotton is placed in each of the lower crucibles to receive the exuded nitroglycerin, and the loss by exudation is determined by weighing the crucibles containing the explosive before and after rotation. The circle of rotation made by the bottom of the crucibles is 14 cm. in diameter, and the standard velocity of rotation is 600 revolutions (30 turns of the handle) per minute. The usual test consists in placing 8 grams of explosive in each of the upper crucibles, and determining the loss in weight after rotating at the velocity of 600 revolutions per minute for 5 minutes at a temperature of about 20° C. If the explosive does not lose more than 5 per cent in weight it is considered to have satisfactory absorbing capacity, but if more than 5 per cent is lost its absorbent properties are considered deficient, and in the transportation or use of such an explosive there is considered to be liability of accident.

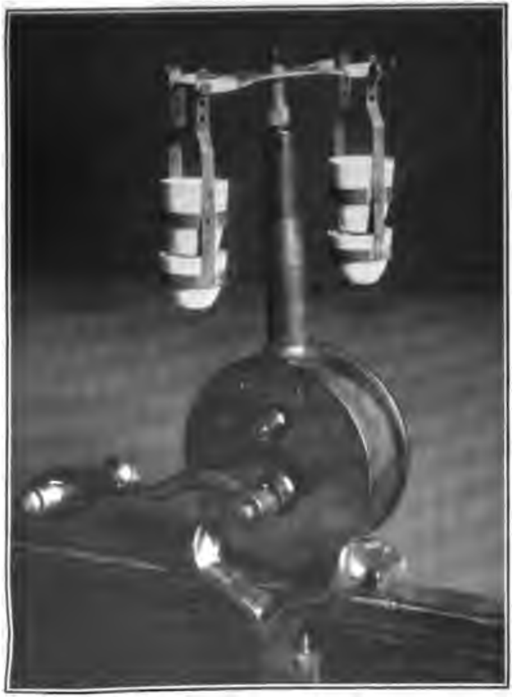
TEST FOR STABILITY.

Many tests have been proposed for determining the stability of explosives under the influence of heat, and much has been written in regard to the comparative accuracy of these different tests. This field is now being investigated by the bureau, and a special report thereon will be issued. At present all mining explosives examined by the bureau are tested for stability by means of the Abel heat test.

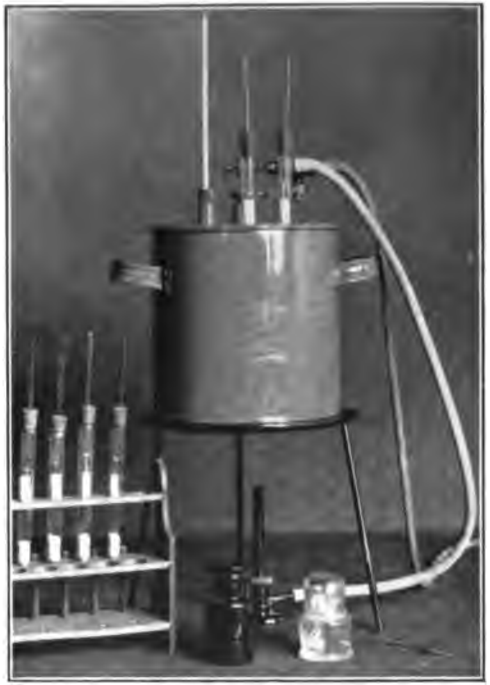
ABEL TEST.

The Abel stability test depends upon the fact that when potassium iodide is decomposed in the presence of starch, the iodine liberated reacts with the starch to form a colored body. The explosive to be tested is placed in a stoppered test tube and heated in a constant-temperature bath until the oxides of nitrogen liberated as decomposition products make a brownish color on a strip of potassium iodide starch paper suspended in the tube above the explosive. The stability of the explosive is judged by the time required for the production of a coloration of a standard intensity. The apparatus used in the Abel test is illustrated in Plate I, *A*.

Two grams of explosive in its original condition, without preliminary drying or preparation other than thorough mixing, is placed in



A. CENTRIFUGE FOR EXUDATION TEST OF DYNAMITE.



B. APPARATUS FOR ABEL HEAT TEST.

a glass tube. The tube is of standard dimensions as follows: Length, 14 cm. (5½ inches); inside diameter, not less than 1.27 cm. (½ inch); outside diameter, not more than 1.59 cm. (⅝ inch); thickness of the glass, about 1.2 mm. (3/64 inch). The tube is closed by a clean, tightly fitting cork stopper, through which passes a glass rod provided with a platinum hook, fused into the lower end for holding the test paper. The test papers, in pieces about 2.5 cm. (1 inch) by 1.0 cm. (⅜ inch), are hung on the platinum hooks (forceps being used in handling) and the upper half of each strip of test paper is moistened with a solution of equal volumes of pure glycerin and water.

The test paper used is potassium iodide starch paper, similar to that prepared by Eimer & Amend (Frankford Arsenal formula), or prepared by a standard method as described below. The heat-test bath is placed so that a good light—not direct sunlight—is transmitted through the test papers to the operator. The bath temperature is maintained constant within 0.5° C. of the desired temperature (71° C.), the thermometer being so immersed that the bottom of the bulb is 2½ inches below the top of the bath.

All determinations are made in duplicate. The shorter time required to bring one of the two test papers to the prescribed tint determines the test of the explosive, except in case of wide variation in results, when two or more additional samples are tested.

After each test the cork stopper of each tube is either discarded or carefully washed and dried and in any case is frequently renewed. The tube and the rod are carefully cleaned after each test, ether or other solvent being used to remove nitroglycerin, etc. They are then washed with water, and finally rinsed with distilled water. All the parts of the apparatus are dried in a steam oven at 100° C. The apparatus is at all times protected from laboratory fumes.

The tube is inserted to a depth of 2½ inches below the top of the bath, the water in the bath being within one-fourth inch of the top. The time of placing the tube in the bath is recorded, and the test is considered completed on the appearance of a brownish line at the lower edge of the moist portion of the paper, of the same intensity as the line on a standard-tint paper prepared as described below. It should be noted, however, that the brownish color on the test paper may at times be spread over a considerable portion of the paper, not forming a sharp, well-defined line. The operator should judge what would be equivalent to the standard tint over a width of one-half to 1 mm.

Caramel standard tint paper.[a]—The tint paper used as a standard color comparator for the test is made as follows: A solution of caramel in distilled water is prepared, of such concentration that when diluted to 100 times its volume (10 c. c. diluted to 1 liter) the tint of the solution equals that produced by the Nessler test on adding 2 c. c. of Nessler reagent to 100 c. c. of water containing 0.000075 gram of NH_3, or 0.0002305 gram of NH_4Cl. With a fine brush or pen dipped into this caramel solution fine lines are drawn on strips of filter paper (Schleicher and Schüll, 597). These strips are cut to the size of the regular test papers (1 inch by ⅜ inch) so that the brown line crosses each piece near the middle of its length. The line should be ½ to 1 mm. in width when dry. A piece of this standard tint paper should be placed in an empty tube beside those being tested, so that a comparison of color may be made.

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[a] 30th Ann. Report H. M. Inspector of Explosives, 1905, p. 236.

Preparation of test paper for Abel test.[a]—The paper used in preparing the test paper is Schleicher and Schüll's filter paper 597. This is cut in strips about 6 by 24 inches, and after being washed by immersing each strip in distilled water for a short time is hung up to dry overnight. The cords on which the paper is hung are clean and the room is free from fumes. The washed and dried paper is dipped in a solution prepared as follows:

The best quality of potassium iodide obtainable is recrystallized three times from hot absolute alcohol, dried, and 1 gram dissolved in 8 ounces of distilled water. Cornstarch is well washed by decantation with distilled water, dried at a low temperature, 3 grams rubbed into a paste with a little cold water, and poured into 8 ounces of boiling water in a flask. After being boiled gently for 10 minutes, the starch solution is cooled and mixed with the potassium iodide solution in a glass trough.

Each strip of filter paper is immersed in the above-mentioned mixture for about 10 seconds and is then hung over a clean cord to dry. The dipping is done in a dim light and the paper left overnight to dry in a perfectly dark room. Every precaution is taken to insure freedom from contamination in preparing the materials and from laboratory fumes that might cause decomposition. When dry the paper is cut into pieces about ⅜ by 1 inch and is preserved in the dark in tight glass-stoppered bottles, the edges of the large strips being first trimmed off about one-fourth inch to remove portions that are sometimes slightly discolored. When properly prepared the finished paper is perfectly white, any discoloration indicating decomposition due to contamination.

SAMPLING.

The first step to be taken in the analysis of dynamite, as with any other material, is the careful preparation of a sample. Dynamite is offered in commerce in the form of cylindrical "sticks" or cartridges, usually three-fourths inch to 1½ inches in diameter and 8 inches long. For special work dynamite is made in cartridges up to 5 inches in diameter, but owing to restrictions in railroad transportation the length of cartridges of dynamite does not vary greatly, and cartridges over 8 inches long are unusual.

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[a] Storm, C. G., Proc. 7th Inter. Congress Applied Chem. 1909; Jour. Ind. and Eng. Chem., vol. 1, 1909, p. 802.

A cartridge of dynamite consists of a covering of paper, sometimes waxed or parchmentized and often coated with paraffin, within which the dynamite is more or less tightly packed to give it the density desired. In the manufacture of dynamite the paper "shell" is first made, and is then packed with the explosive, after which the cartridge is sometimes "redipped," by which is meant that the cartridge is plunged into a bath of paraffin heated slightly above its melting point. The paraffin closes any openings in the wrapper and tends to make the cartridge waterproof. This operation of "redipping" is of interest in connection with the analysis of explosives chiefly because of the opportunity it affords for the entrance of paraffin into the explosive. When a paper shell is not perfectly made some paraffin is apt to find its way through the paper shell and be absorbed by the wood pulp. In sampling, care should always be taken to remove any paraffin that has found access through the ends of the cartridge, since obviously such paraffin is not to be considered as a normal constituent of the explosive, and care should also be taken in unwrapping the cartridge to prevent scales and flakes of paraffin from becoming mixed with the sample.

The best method of sampling consists in opening the wrapper of each cartridge, spreading it out and cutting off from 3 to 5 cm. from each end of the roll of explosive thus exposed. These ends are rejected and the remainder carefully broken up to form a homogeneous mass. When a sample representing a large quantity of powder—for example, a day's output of a factory—is to be prepared, a number of cartridges are taken from different mixings, the central portions of each cartridge are selected in the manner described, and these portions are finely broken up in a large porcelain evaporating dish or on a sheet of paraffined paper. The mass is carefully stirred with a clean spatula, or is rolled from side to side upon the paraffined paper in the manner usually followed in preparing a sample of ore for assay. The stirring of the sample, or its rolling back and forth upon the paraffined paper, should occupy not less than five minutes, and the best results are obtained from such sampling when the explosive has been previously broken up to as fine a meal as possible by crumbling in the fingers or by gentle pressure with the spatula. A spatula suitable for this purpose is made of horn, or of wood saturated with paraffin so that it will not absorb nitroglycerin.

From the large sample prepared as described a sample of 50 to 100 grams is taken by selecting small portions from different parts of the mixed material, mixing these portions, and placing the mixture in the sample bottle.

In preparing a sample of dynamite there are several factors that must be constantly borne in mind. If a thoroughly mixed sample is prepared and allowed to remain for some time in a sample bottle, a segregation occurs, and the lower portions of the material in the sample bottle become richer in nitroglycerin at the expense of the upper portions. In some dynamites, particularly one that contains almost as much nitroglycerin as its absorbent base can hold, this change occurs rapidly, and may make a difference of several per cent in a few days. The tendency to segregate is greatest in a tall bottle, and is favored by warmth, the action taking place several times as rapidly at 30° C. as at 20° C. An indication of the amount of segregation that is possible in dynamite is seen from the results of the following experiment:

A sample of dynamite was prepared by carefully breaking up and sampling two sticks of 60 per cent dynamite, about 300 grams being taken and placed in an ordinary bottle of 250 c. c. capacity (diameter about 6 cm., height about 14 cm.). At the time the sample was placed in the bottle the analysis of the material gave the following results:

Analysis of 60 per cent dynamite.

[W. C. Cope, analyst.]

	Per cent.
Moisture	1.40
Nitroglycerin	60.60
Potassium nitrate	18.64
Calcium carbonate	1.25
Wood pulp	18.11

At the end of 10 days' exposure to a temperature of 32° to 33° C. (average, 32.5° C.) samples were taken from the top, middle, and bottom of the material in the bottle, and the following results were obtained:

Analyses of different parts of exposed sample of 60 per cent dynamite.

[W. C. Cope, analyst.]

Constituents.	Sample from top.	Sample from middle.	Sample from bottom.
	Per cent.	*Per cent.*	*Per cent.*
Moisture	1.25	1.16	1.17
Nitroglycerin	59.46	60.55	62.86
Potassium nitrate	19.91	18.44	17.42
Calcium carbonate	1.37	1.33	1.26
Wood pulp	18.01	18.52	17.29

Another experiment was made to illustrate segregation in cartridges themselves.

Whole cartridges of 40 per cent, 45 per cent, and 60 per cent dynamite were placed upright (on end) in a constant-temperature oven at 40° for a period of four weeks, the cartridges being supported by small wire tripods within glass cylinders. Pinholes were punched in the bottom of the wrappers to allow the escape of any accumulation of nitroglycerin, but no such leakage occurred.

At the end of four weeks samples were taken from the top and bottom of each cartridge, each sample representing about a 2-inch length of cartridge. The following results of analyses of these samples show the segregation of the nitroglycerin:

Analyses of parts of samples of dynamite left standing on end for four weeks at 40° C.

[J. H. Hunter, analyst.]

Grade of dynamite, per cent	40	45	60
Part of cartridge sampled.	Nitroglycerin.		
	Per cent.	*Per cent.*	*Per cent.*
Top	38.20	45.07	57.27
Bottom	40.96	47.98	63.26

From the above described experiments it will be seen that the sampling of dynamite involves problems not met in the preparation of ore for assay.

To determine any possible segregation due to nitroglycerin adhering to the dish in which a sample is mixed, 500 grams of dynamite was mixed in a large evaporating dish, and, when thorough mixing had been effected, was poured on a piece of paraffined paper. An analysis was then made of the large sample upon the paraffined paper, and the material adhering to the sides of the evaporating dish was removed by means of ether and analyzed. It was found that there was little difference between the composition of the two samples. It has been suggested that considerable changes in the moisture content of dynamite can occur during sampling, but this opinion does not seem correct. In the factory dynamite is usually mixed in an open mixer exposed to the atmosphere; consequently the percentage of moisture taken up or lost in the short length of time that the explosive is exposed to the air during sampling should be proportional only to the difference between the hygrometric condition of the air at the time the dynamite was made and that at the time it was sampled. To investigate this question further an experiment was made as follows:

Two cartridges of one-half pound (226 grams) each were mixed together quickly, and with as little exposure to the air as possible. This original sample was found to contain 1.10 per cent moisture.

A 100-gram portion of this large sample was then mixed on a large watch glass for 10 minutes on a damp day when the humidity of the air as determined by hygrometer readings was 75 per cent. Another 100-gram portion was similarly treated on a dry day when the humidity was only 19 per cent. Determinations of moisture were then made on these two portions with the following results:

Effect of exposure during sampling on moisture content of dynamite.

Treatment of sample.	Moisture.
	Per cent.
Without undue exposure	1.10
Stirred 10 minutes in moist atmosphere	1.25
Stirred 10 minutes in dry atmosphere	1.10

From these results it will be seen that the condition of the atmosphere has little effect on the moisture content of a sample when the sampling is done with reasonable dispatch and when atmospheric conditions are not abnormal.

CHEMICAL EXAMINATION.

QUALITATIVE EXAMINATION.

When no information is available as to the class to which an explosive to be analyzed belongs, a complete qualitative analysis is desirable, so that the proper methods of quantitative separation may be followed.

For the qualitative examination of a dynamite of any type a sample of 20 to 25 grams is most convenient. The sample is placed in a 1-inch test tube, which is then filled to about two-thirds of its depth with ether, stoppered, and well shaken. The ether is decanted through a filter paper and fresh ether is added to the tube. This treatment is repeated several times, and the residue is finally transferred to the filter and again washed with fresh ether. After the ether is drained off, the filter paper with its contents is removed from the funnel, spread out on a glass plate, and placed in a drying oven for a short time until nearly all the ether has evaporated. The dry residue is transferred from the filter back to the test tube, and is then ready for treatment with cold water, to remove the water-soluble constituents.

The ether solution is evaporated on a steam bath or electric heater at a low temperature until all odor of ether has disappeared. If the evaporation has caused the deposition of water in the beaker with the extract, this water is removed by placing the beaker in a vacuum desiccator for an hour or two. The presence of nitroglycerin is readily noted, the characteristic oily appearance of nitroglycerin and its viscosity serving to identify it. A convenient chemical test is to mix a drop of the heavy liquid, supposed to be nitroglycerin, with 1 or 2 c. c. of concentrated sulphuric acid in a test tube, and then to add about 1 c. c. of mercury. No stopper of any sort should be placed in the tube, but it should be shaken quickly from side to side so as to cause intimate contact of the mercury with the acid mixture. For 1 or 2 minutes little effect will be observed, but after a short time there will be noted, if the material under examination is nitroglycerin, the evolution of bubbles of gas from the liquid at the point where it comes in contact with the mercury, and the characteristic smell of nitrogen oxides will be noted. The nitric oxide (NO) produced is colorless, but upon coming in contact with the air it turns red or reddish-brown, forming nitrogen peroxide (NO_2). A simpler test for the presence of nitroglycerin, though by no means so satisfactory as the one just described, consists in taking up a small amount of the liquid in a capillary glass tube, and holding it cautiously in a flame. A strong detonation will result if the liquid is nitroglycerin. It is of course evident that there should be not more than a tiny fraction of a drop of nitroglycerin used in such a test, the best results being obtained when a very thin and small capillary is used, containing not more than 0.01 of a drop of the liquid tested.

If sulphur is present in the ether extract it will crystalize in needles or small granular masses in the residue upon the evaporation of the ether. The crystals of sulphur can be removed, washed free from nitroglycerin with a little acetic acid (70 per cent or glacial), after which they should be washed with water, dried, and heated over a flame. The odor of sulphur dioxide (SO_2) will identify the crystals as sulphur. Trinitrotoluene appears as long yellowish needles, which may be recrystallized from alcohol and identified by their melting point (80° C.), or by the color test with potassium or sodium hydroxide.[a] This color test is valuable as a means of identifying many of the nitrosubstitution products, although in a mixture the color produced by one constituent may completely hide the others. For example, the wine-red color obtained from trinitrotoluene may prevent the identification of other nitrocompounds that may be present. The test may be made directly on a portion of the ether extract, since the presence of nitroglycerin does not in any way interfere. The sample under examination is dissolved in 2 to 3 c. c. of acetone or methyl alcohol, and a few drops of 10 per cent potassium or sodium hydroxide added. The characteristic colors produced by various nitrosubstitution compounds are shown in the table following.

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 599.

Color reactions of nitrosubstitution products with alkalies.

Substance.	Form.	Color of solution.	Result of addition of alkaline solution.
Mononitrobenzene	Liquid	Colorless	No effect.
Dinitrobenzene	Crystal	Faint yellow	Purple-rose, turning to deep claret.
Trinitrobenzene	do.	Colorless to pale yellow.	Rich purple-brown.
Mononitrotoluene (ortho)	Liquid	do.	No effect.
Mononitrotoluene (meta)	Crystal	do.	Slight yellow.
Mononitrotoluene (para)	do.	do.	No effect.
Dinitrotoluene	do.	do.	Gradual evolution of azure blue on standing.
Trinitrotoluene	do.	do.	Deep wine-red brown.
Mononitronaphthalene	do.	do.	No effect.
Dinitronaphthalene	do.	Pale yellow	Reddish-yellow.
Trinitronaphthalene	do.	do.	Bright scarlet.
Tetranitronaphthalene	do.	do.	Reddish-yellow.
Picric acid	do.	Golden-yellow	Precipitate of crystals of potassium picrate (orange).

Rosin, vaseline, paraffin, oils, etc., are found in the extract, after evaporation of the ether, as a dark-colored, greasy mass on the surface of the nitroglycerin or adhering to the walls of the beaker. Small amounts of resins and oils are generally found in the extracts from ordinary dynamite, these being normal constituents of the wood pulp, flour, or similar absorbents. The amount of such materials present is usually too small to be of any importance, and where only small traces are found they may best be disregarded. If it is desired to identify such materials the method for quantitative determination described later may be followed.

The water solution is examined for sodium, potassium, ammonium, zinc, the nitrate ion, etc. The qualitative and quantitative tests for these elements are discussed fully in all textbooks of analysis, and accordingly need not be repeated here. In ordinary qualitative work the writers have found the ring test for nitrates, with the use of the nitrometer in any doubtful case, to be most satisfactory; potassium and sodium are best identified by the color they impart to the flame of the Bunsen burner, viewed through at least two thicknesses of cobalt glass. The best test for ammonium is the evolution of ammonia by reaction with calcium oxide or sodium hydroxide. Small quantities of iron, aluminum, chlorides, sulphates, etc., are generally found in all dynamites as impurities from the raw materials used.

The residue insoluble in water is treated with cold dilute hydrochloric acid; effervescence, if noted, is an indication of the presence of a carbonate, and the usual tests are then made for CO_2. The acid extract after filtering is tested for calcium, magnesium, zinc, etc., whose carbonates or oxides may have been present in the powder as antacids.

The residue insoluble in water and dilute acid is best examined under the microscope, a magnification of 30 to 50 diameters being most convenient for all ordinary work. The identification of starch, cereal products, wood pulp, sawdust, kieselguhr, nitrocellulose, etc., is discussed in another part of this paper.

A starch test is readily made by heating a portion of the material to boiling with dilute acid, cooling and adding a drop of iodine solution, this operation producing an intense blue coloration if starch is present.

DETERMINATION OF MOISTURE.

The moisture present in dynamite may be determined in the following ways:

(*a*) By drying in a desiccator over sulphuric acid, calcium chloride, or other suitable drying agent without vacuum.

(*b*) By drying in a desiccator with vacuum.

(*c*) By passing dry air through the sample.

These methods have been carefully studied, and the first method, drying over sulphuric acid in a desiccator, has been found to have the widest application, and to be the most desirable in the analysis of explosives. In the determination of moisture in a sample of dynamite a number of important factors should be considered in order that accurate results may be obtained. The weight of the sample, the manner in which the sample is spread upon the watch glass, the size and type of desiccator, the exposed area of the desiccating agent, as well as its quantity and condition and the temperature at which the desiccation is carried out—all have an important bearing on the loss of weight resulting from desiccation, and unless care is taken moisture determinations made at different times on the same sample of dynamite will frequently give somewhat different results, owing to the slight variations in some of the above-named factors.

Preliminary studies were made to determine the amount of dynamite that is most suitable for the determination of moisture, and the thickness with which the sample should be spread upon the watch glass. The results of these tests showed that a sample of less than 2 grams of explosive is unsatisfactory, owing to the errors introduced, for example, by particles of material being carried away by the air during weighing, or upon opening the desiccator. When more than 2 grams of sample was taken the length of time required to effect thorough drying was unduly long; and consequently 2 grams of material, spread evenly on the concave surface of a 3-inch watch glass, was deemed the best amount for the determination. When only one or two analyses have to be run at a time, it is convenient to use a separate 5 or 6 inch desiccator for each sample, the bottom of the desiccator containing about 50 to 75 c. c. of concentrated sulphuric acid, and the watch glass being held by a triangle at a convenient and suitable distance above the acid. Objections have been raised[a] to the use of sulphuric acid as a desiccating agent in the determination of moisture in dynamite. The experience of the writers has shown these objections to be without grounds.

When a number of determinations are being made at the same time it is convenient to use larger desiccators, and the 10-inch size has been found to be satisfactory, five watch glasses being conveniently held at one time in such a desiccator.

IN ORDINARY DESICCATORS.

The period required for desiccation of a sample of dynamite in an ordinary desiccator is about 3 days or 72 hours. The first 12 hours within the desiccator reduces the moisture content to a very low percentage, but it has been found desirable to allow all samples to remain a further period of 60 hours, as the remainder of the moisture is slowly removed. The loss in weight, at the end of three days, of the 2-gram sample of dynamite on the watch glass is taken as moisture. After three days' drying, small amounts of moisture are still present, particularly in the wood pulp, but drying longer than three days has not been found desirable in ordinary analytical work. By long-continued desiccation, over either calcium chloride or sulphuric acid, a further gradual loss occurs which is evidently due to volatilization of nitroglycerin, and the amount of this loss varies with the temperature. Taking the loss of weight at the end of three days as representing moisture has been found to give uniform results in the case of dynamites of most varied composition, and has been adopted in the bureau's laboratory as a standard method, although it is impossible to say that at the end of any definite time all moisture has been removed from the sample and that further loss is due to volatilization of nitroglycerin.

Care should always be taken to spread the sample in a thin and uniform layer over nearly the entire surface of the watch glass, and the spreading should be done as quickly as possible to prevent undue exposure to the atmosphere. Experiments in which different sizes of desiccators (4-inch to 9-inch) were used showed that the rate of drying increased as the ratio of acid surface to powder surface increased, but that in three days the loss in all cases was practically the same. The effect of such variation is shown in the following table of results of tests of explosives containing amounts of moisture greater than that in ordinary dynamite. The table also shows a comparison between the efficiencies of two types of desiccators—the Scheibler, or ordinary type, which contains the acid in the bottom below the sample, and the Hempel type in which the acid is contained in the top or cover, above the sample. With an acid surface about 75 per cent as great as in the ordinary type the Hempel desiccator appears to be slightly more efficient than the Scheibler.

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 382; Guttmann, O., Schiess- und Sprengmittel, 1900, p. 162.

Results of moisture determinations showing effect of variation in acid surface and in type of desiccator.

Type of desiccator		Scheibler.	Scheibler.	Hempel.
Size of desiccator		4-inch.	9-inch.	6-inch.
Area of acid surface (approximate)		7 square inches.	50 square inches.	38 square inches.
Name of explosive.	Time of drying.	Moisture content determined by loss of weight.		
	Hours.	*Per cent.*	*Per cent.*	*Per cent.*
Explosive A[a]	6	5.73	9.84	9.97
	12	8.82	10.11	10.29
	24	10.06	10.33	10.43
	48	10.52	10.63	10.65
	72	10.66	10.68	10.79
Explosive B[a]	2	1.89	....	3.18
	5	4.09	....	4.88
	24	5.34	5.50	5.51
	48	5.49	....	5.60
	72	5.50	5.59	5.63

[a] Arbitrary designation of sample.

The quantity of acid used in the desiccator must also be considered, because the dilution of the acid by the absorbed moisture is dependent upon the amount of acid present. In general, the acid contained in a desiccator does not require frequent renewal, and when from 50 to 75 c. c. of concentrated sulphuric acid (H_2SO_4) is used in the desiccator the renewal of this material once each month or once every two months is all that is necessary.

The following experiment illustrates the effect of dilution of the sulphuric acid by the absorption of considerable moisture from powder samples. Two samples of the same dynamite were desiccated in similar desiccators, one containing 75 c. c. of 96 per cent sulphuric acid, the other the same volume of 90 per cent sulphuric acid. In three days the losses of moisture were 1.10 per cent and 1.02 per cent, respectively, and in five days 1.17 per cent and 1.05 per cent, respectively. In order that 75 c. c. of 96 per cent acid could become diluted to 90 per cent by the absorption of moisture from dynamite samples, it would be necessary that all of the moisture from about 460 2-gram samples of dynamite, each containing 1 per cent moisture, be absorbed by the acid. It is therefore obvious that the acid in the desiccators will not become diluted enough in one or two months to lose appreciably its affinity for moisture.

The effect of temperature on the moisture determination is shown in the following experiments, made with a 60 per cent dynamite. Three determinations of moisture were made on the same sample at widely different temperatures. Two grams of the sample in one desiccator were placed in an incubator, the temperature of which, by means of a thermostat, was regulated to a range of 36° to 38° C. (96.8° to 100.4° F.). A second desiccator containing another 2 grams of the sample was placed out of doors, the temperature varying during the experiment from −23° to 2° C. (−9.4° to 35.6° F.). A third desiccator containing a third 2-gram portion of the sample was left at room temperature, which varied from 17° to 25° C. (63° to 77° F.). In each of these experiments the 2-gram parts of the sample were spread upon 3-inch watch glasses, each watch glass being placed in a separate 4-inch desiccator containing 75 c. c. of fresh sulphuric acid. The results are tabulated below:

Results of tests to determine the moisture content of dynamite, showing the influence of temperature.

1	2			3	4	5		6	
Sample No.	Temperature.			Days. exposed.	Loss of weight on desiccation.	Ether extract.		Nitroglycerin in ether extract.[a]	
	Maximum.	Minimum.	Mean.			By loss.	By direct weight.		
	°C.	°C.	°C.		Per cent.	Grams.	Grams.	Grams.	Per cent.
				3	1.00				
				6	1.06				
1	25	17	21	7	1.06				
				10	1.19				
				13	1.31	1.2158	1.2126	1.2051	60.26
				3	1.69				
				6	2.49				
2	38	36	37	7	2.74				
				10	3.54				
				13	4.12	1.1563	1.1522	1.1397	56.99
	−7	−16		3	0.60				
	−3	−23		6	....				
3	0	−14	−9	7	0.72				
	2	− 9		10	0.67				
	20	18	19	13	1.03	1.2243	1.2220	1.2114	60.57

[a] Determined by nitrometer.

After the weighings had been made on the thirteenth day the samples were carefully transferred to Gooch crucibles, and extracted with ether in a Wiley extractor.[a] The crucibles were then dried at 100° C., and the losses in weight determined, which are given in column 5. The nitroglycerin in each sample of ether extract was then determined by the nitrometer after the ether had been evaporated (see p. 35). The results shown under "loss of weight by desiccation" (column 4) indicate the pronounced influence which temperature has on the determination of moisture. In the case of sample 2 most of the moisture was probably lost within the first 24 hours, the further loss being entirely due to the evaporation of nitroglycerin. In the case of the sample 3 the weight first taken, at the end of three days, showed a loss of only 0.60 per cent. As previous experiments had shown that this amount of moisture can be removed from 60 per cent dynamite by about two hours' desiccation, it is probable that the loss noted during the first three days resulted during the first two hours' desiccation, before the sample became frozen. Practically no further loss occurred in this sample up to 10 days, and the loss which occurred between the tenth and thirteenth day was due to the fact that the sample had thawed. As the temperature in the laboratory frequently reaches 35° C. or more during the summer, it is evident that abnormally high results sometimes obtained during warm days of summer may be in error to a considerable extent, being only in part due to loss of moisture and in part to volatilization of nitroglycerin. Since incorrect results are obtained when moisture is determined at a low temperature, no determinations of moisture should be made at a temperature sufficiently low to cause the sample to freeze. In order that perfectly uniform results may be obtained with samples of dynamite, the temperature of the room in which the desiccation is carried out should be practically constant at 20° C. This is a normal working temperature, and when moisture determinations are made at temperatures materially above or below it, allowance should be made for the influence of the abnormal temperature. The results given in the table on p. 22 are shown in the form of curves in figure 1. The curve for sample 3 represents the results

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[a] For the method used in the extraction see p. 30.

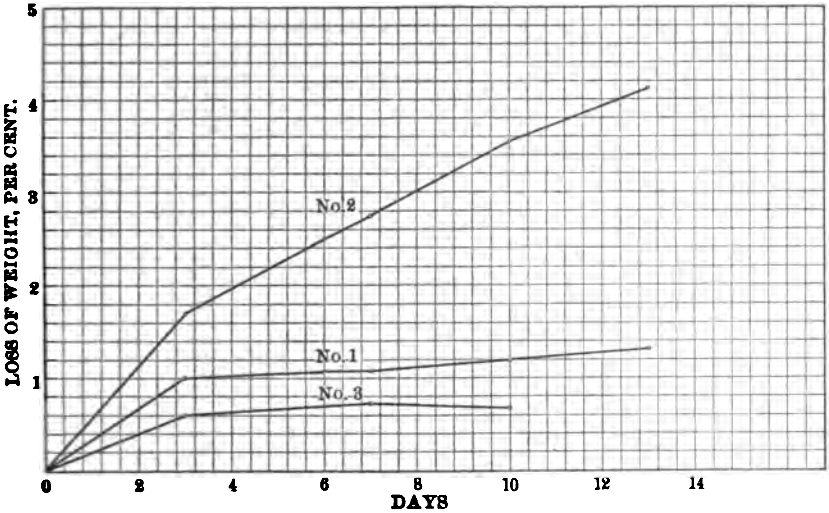

FIGURE 1.—Influence of temperature on determination of moisture in 60 per cent dynamite by desiccation over sulphuric acid. Temperature (mean): No. 1, 21° C.; No. 2, 37° C.; No. 3, —9° C.

of the first 10 days' exposure, during which period the sample remained frozen.

In the determination of moisture by the bureau's explosives laboratory, sulphuric acid has been accepted as the standard desiccating agent. As many chemists prefer to use calcium chloride, the following experiment is of interest, as showing the difference in efficiency of these two desiccating agents. Six 2-gram samples of 60 per cent dynamite were weighed from a large, well-mixed sample. Three of these samples were desiccated over calcium chloride and three over sulphuric acid. An individual 6-inch Scheibler desiccator was used for each sample. Weighings made at intervals showed the loss of moisture as follows:

Results of desiccation of 60 per cent dynamite over calcium chloride and over sulphuric acid, at room temperature.

Time.	Designation of sample.	Loss of weight over calcium chloride.	Designation of sample.	Loss of weight over sulphuric acid.
Days.		*Per cent.*		*Per cent.*
$\frac{1}{12}$	A	0.50	C	0.64
$\frac{1}{4}$	A	.59	C	.73
$\frac{1}{2}$	A	62	C	.79
$\frac{3}{4}$	B	.66	D	.87
1	A	.67	C	.84
2	B	.77	D	.94
3	A	.77	C	.96
3	B	.80	D	.97
3	E	.84	F	1.02
5	A	.84	C	1.01
5	B	.87	D	1.01
5	E	.91	F	1.07
6	A	.84	C	1.02
6	A	.87	D	1.05
6	E	.93	F	1.10
10	A	.95	C	1.11
10	B	1.00	D	1.17
10	E	1.00	F	1.20
13	A	1.07	C	1.23
13	B	1.10	D	1.32
13	E	1.15	F	1.36
16	A	1.16	C	1.33
16	B	1.13	D	1.46
16	E	1.25	F	1.48
19	E	1.25	F	1.53
20	E	1.37	F	1.60
34	E	1.72	F	2.01
50	E	2.22	F	2.55
75	E	2.82	F	3.35
111	E	3.67	F	4.55
183	E	5.77	F	7.55
237	E	6.85	F	9.20

These results, plotted in the form of curves for the two samples E and F, upon which desiccation was continued the longest, are shown in figure 2.

The fact that nitroglycerin is more or less volatile even at ordinary temperatures is recognized by most explosives chemists, and in some laboratories an endeavor is made to avoid loss of nitroglycerin during desiccation by keeping the atmosphere within the desiccator saturated with nitroglycerin vapors. This is done by placing in the desiccator, together with the sample of dynamite on which moisture is to be determined, a quantity of nitroglycerin on a watch glass, it being assumed that the evaporation of this nitroglycerin will saturate the atmosphere in the desiccator and minimize the loss of nitroglycerin from the sample of dynamite.

To test the value of such method the following experiments were made: Four samples (2 grams each) of the same 60 per cent dynamite used above were spread on 3-inch watch glasses and placed in separate desiccators. Directly underneath each of the watch glasses was placed a watch glass containing a layer of fine dry sand saturated with nitroglycerin. Two of the desiccators contained sulphuric acid and two calcium chloride. Weighings of the dynamite samples at intervals showed losses of weight as follows:

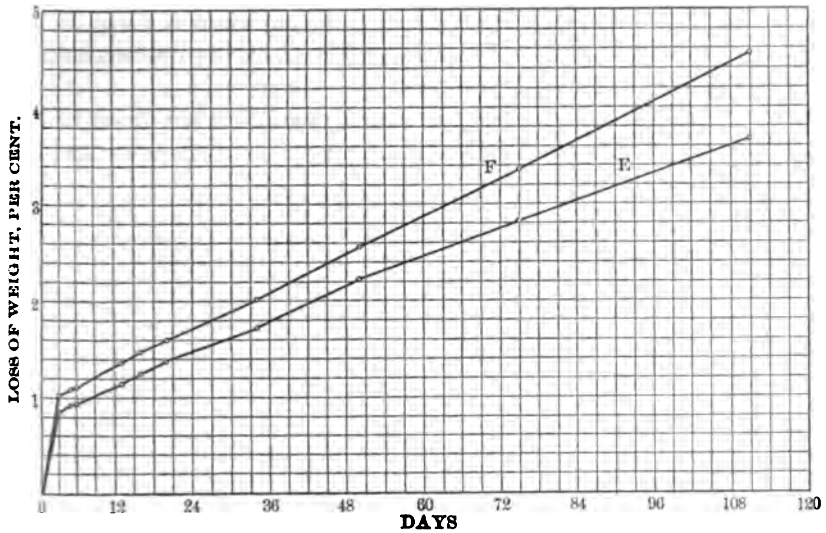

FIGURE 2.—Results of desiccation of 60 per cent dynamite over calcium chloride (E) and over sulphuric acid (F) at room temperature.

Results of desiccation of 60 per cent dynamite over calcium chloride and over sulphuric acid in an atmosphere saturated with nitroglycerin vapors.

Designation of sample.	Desiccation over calcium chloride.		Designation of sample.	Desiccation over sulphuric acid.	
	Time.	Loss of weight.		Time.	Loss of weight.
	Days.	*Per cent.*		*Days.*	*Per cent.*
A	3	0.77	C	3	....
B	3	.80	D	3	0.92
A	6	.93	C	6	1.10
B	6	.97	D	6	1.12
A	10	1.02	C	10	1.13
B	10	1.00	D	10	1.15
A	13	1.15	C	13	1.20
B	13	1.17	D	13	1.25
A	19	1.25	C	19	1.31
B	19	1.35	D	19	1.40

Comparing these results with those of the table on page 24, it will be noted that the placing of an additional amount of nitroglycerin in the desiccator with the sample of dynamite has practically no effect on the amount of nitroglycerin lost from the sample.

The fact that nitroglycerin volatilizes in the desiccator in the presence of either sulphuric acid or calcium chloride suggested the carrying out of experiments to determine whether a sample of dynamite that had been desiccated for a sufficient time to lose all of its moisture would continue to lose weight in an empty desiccator (without any desiccating agent present).

Two 2-gram samples of 60 per cent dynamite were dried for three days on watch glasses over sulphuric acid, and then immediately placed in clean desiccators without any drying agent. One of these was kept at room temperature (17° to 22° C.), the other in a constant-temperature incubator oven at a temperature of 33° to 35° C. Weighings made at intervals showed a continued steady loss from the sample at 33° to 35°, whereas the sample exposed to room temperature gained in weight at first, then steadily lost until at the end of about 40 days it had attained its original weight. In the table below the percentage of loss or gain in weight recorded represents the variation from the dry weight of the samples after having been desiccated three days.

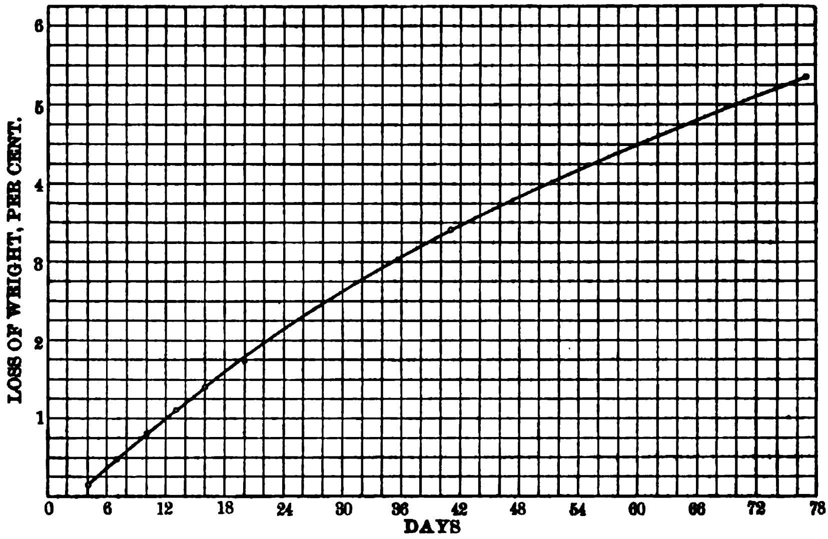

FIGURE 3.—Result of exposure of dry 60 per cent dynamite in a desiccator at 33° to 35° C. without desiccating agent.

Change in weight of dried samples of 60 per cent dynamite in desiccators containing no desiccating agent.

Time in desiccator.	Change in weight.		
	Sample *A* (17°-22° C.).		Sample *B* (33°-35° C.).
	Gain.	Loss.	Loss.
Days.	*Per cent.*	*Per cent.*	*Per cent.*
4	0.36	....	0.13
7	.35	....	.46
10	.30	....	.80
13	.25	....	1.10
16	.20	....	1.40
20	.20	....	1.75
41	....	0.05	3.40
77	....	.67	5.35
202	....	2.63	9.33

It is often desirable to make a weighing at a shorter interval than 72 hours, and to obtain an approximation of the true moisture by calculation. An extended series of tests was made to determine what factor could be safely used, in conjunction with a weight taken at the end of 24 hours, to give the same result as would be obtained by desiccation for a period of 72 hours. It was found that the influence of the temperature of the room in which the desiccator was kept was so marked, and the difference in effect between different desiccating agents,[a] was such as to make this method uncertain. At the best only an approximation can be obtained, but when time is more important than accuracy a rough approximation to the true moisture content of ordinary dynamite can be obtained by considering the loss in weight over sulphuric acid in 24 hours to be 90 per cent of the total moisture. In other words, the loss of weight in 24 hours' desiccation multiplied by the factor 1.11 will be an approximation to the true moisture content. When large amounts of moisture are present, as in certain types of coal-mining explosives containing water added as a constituent of the explosive, it is not advisable to attempt the use of such a factor. In such cases the loss of weight on desiccating three days is considered as the total moisture.

IN VACUUM DESICCATORS.

The evaporation of water is much more rapid at reduced pressure than under atmospheric pressure, and therefore the determination of moisture may be made in a shorter time with the use of a vacuum than when atmospheric pressure prevails within the desiccator. If nitroglycerin were perfectly nonvolatile, desiccation in a vacuum would probably be sufficiently reliable for use as a standard method.

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[a] See table on p. 24.

The following table shows the results obtained when samples of the same dynamite were exposed in desiccators of similar size and shape that contained the same desiccating agent, in one case a vacuum being used and in the other case the air within the desiccator being at the pressure of the air in the room.

Results of desiccating tests with and without vacuum in the desiccator.

Time dried.	Sample in ordinary desiccator.	Sample in vacuum desiccator.
	Per cent.	*Per cent.*
Loss of moisture in 24 hours	5.34	5.42
Loss of moisture in 48 hours	5.49	5.63
Loss of moisture in 72 hours	5.68	5.80

With the ordinary type of desiccator, containing acid in the bottom, moisture is removed from the sample much more rapidly with a vacuum than without, other conditions being equal. For example, in a 4-inch desiccator, with 7 square inches of acid surface on which the pressure was that of the atmosphere, the loss of moisture from a powder sample containing about 11 per cent of water was only 54 per cent of the total in 6 hours, 83 per cent in 12 hours, and 94 per cent in 24 hours. In a slightly larger desiccator of the same type, with 12 square inches of acid surface, above which there was a vacuum, the loss in 6 hours was 91 per cent, in 12 hours 95 per cent, and in 24 hours 96.5 per cent. In both samples a practically constant value was obtained in 3 days.

In the case of the Hempel desiccator, containing acid above the explosive sample, the rate of loss of moisture is nearly the same with or without vacuum.

In general it may be stated that any type of vacuum desiccator will remove in 12 hours practically all the moisture from dynamites and even from permissible explosives containing as much as 10 to 12 per cent of water, the result thus obtained being about the same as that given by 3 days' desiccation without vacuum.

Vacuum desiccation for a longer time than 12 hours will cause a further slight loss, which is probably for the most part due to volatilization of nitroglycerin.

IN A DRY-AIR CURRENT.

When a current of air previously dried by being passed through a calcium chloride tube, or through sulphuric acid, is passed through a mass of dynamite in a suitable sample tube, the dynamite gives up its moisture to the dry air. Drying may be very quickly effected in this manner, because of the fact that the dry air comes into intimate contact with all portions of the explosive, but the method has the serious defect of being inaccurate, owing to the volatility of nitroglycerin.

In desiccation by means of dry air, a drying tube of the form shown in figure 4 is usually employed. Sometimes several of these tubes are connected together in a train. The dry air is always introduced at the bottom, so that it may rise through the explosive, and a weighed sample of about 15 grams is generally taken for the determination.

Several tests were made to determine the accuracy of this method of drying samples of dynamite. A current of air dried by passing through sulphuric acid was passed through a sample of dynamite which had been found, by desiccation for three days over sulphuric acid, to contain 5.68 per cent of moisture. Weighings at intervals showed loss of weight as follows.

Loss of weight of dynamite in a current of dry air.

Time dried.	Loss of weight.
Hours.	*Per cent.*
2	1.47
6	4.29
12	5.20
24	5.50
48	5.70
60	5.80
72	5.86

The table shows that at the end of 48 hours there had been a loss in weight approximately corresponding to the percentage of moisture found in the explosive by the standard method. The constant loss after that point represents volatilization of nitroglycerin, although it is of course to be noted that the loss of nitroglycerin was continuous, nitroglycerin being removed from the time the air first began to pass through the sample. How inaccurate this method is may be readily understood when one remembers that nitroglycerin can be completely volatilized by bubbling dry air through it for a sufficient length of time, and that accordingly any sample of dynamite would probably reach an ultimate value in which the loss in weight would correspond to the amount of moisture plus the amount of nitroglycerin present in the sample.

SUMMARY.

The most satisfactory method for the determination of moisture consists in using a 3-inch watch glass containing an evenly distributed 2-gram sample, the watch glass and sample being placed in a desiccator containing sulphuric acid, and being weighed at the expiration of 72 hours. Care should be taken that the temperature does not vary widely from a mean of 20° C. An approximation of the true moisture content of the sample of explosive may be obtained by desiccating in the manner just described for a period of 24 hours, and multiplying the loss in weight thus found by the factor 1.111, or the loss in a vacuum desiccator for 24 hours may be taken without further calculation as an approximation to the true moisture content as determined by standard methods.

EXTRACTION WITH ETHER.

Extraction with ether removes from dynamite not only nitroglycerin, but also any resins or sulphur that may be present. Aside from resin intentionally admixed there is always some resin present in the wood pulp. In addition to these constituents, in dynamite small amounts of oil are sometimes found, having been introduced from mixing machines or packing machines. When flour, corn meal, or other grain or cereal products are present as constituents of explosives a small amount of oil from such materials is also found in the ether extract. Nitrotoluenes, paraffin, vaseline, etc., are not normal constituents of ordinary dynamite, and the determination of these substances is discussed under the type of explosive in which they occur as characteristic components, but it is to be noted that were any of these materials present in dynamite they would be found in the ether extract.

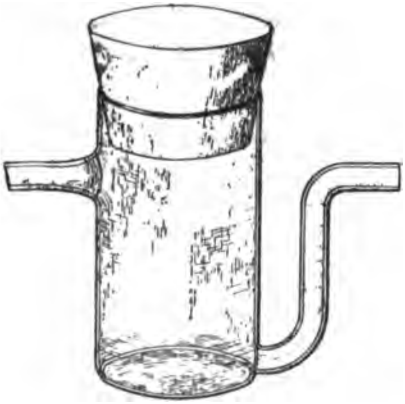

FIGURE 4.—Drying tube.

REFLUX-CONDENSER METHOD.

A sample of from 6 to 10 grams of the explosive is weighed in either a porcelain Gooch crucible with asbestos mat or a porous alundum[a] crucible of about 25 c. c. capacity. When a Gooch crucible is used the mat should be light, but should be perfectly coherent. Such a mat is prepared in the bureau's explosives laboratory as follows: Five grams of short-fiber asbestos, in the form of short shreds, free from hard lumps, is added to 1 liter of water. When used the mixture is well shaken and about 10 c. c., an amount sufficient to fill the crucible to about two-thirds of its depth, is poured into the crucible. Suction is applied, and a smooth and perfect mat is almost invariably produced. The crucible and mat are then carefully dried for some hours at 100°, weighed, and placed in a desiccator. For extracting with ether, the form of apparatus found most satisfactory is the

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[a] A trade name for artificially prepared porous aluminum oxide.

Wiley extractor, as shown in Plate II, *A*. The crucible is supported on a small hanger made by twisting No. 18 copper wire into suitable shape.

In performing an extraction the crucible, with its weighed sample of explosive, is placed in the hanger, and about 35 c. c. of U. S. P. ether (96 per cent) is poured in several portions through the sample into the glass extraction tube. Water is continuously circulated through the cooling coils of the condenser. The ether is boiled by means of an electric heater or a vessel of hot water in which the lower part of the tube is immersed. The ether vapor condenses on the surface of the metal condenser, the condensed ether dropping into the crucible and percolating through the sample of explosive. The temperature is regulated so that the sample will be kept covered with ether without any overflow.

When a vessel of hot water is used for heating the tube, the ether partly drains out of the crucible during a change of water, but is at once replaced by a fresh supply. This intermittent action probably accomplishes a more efficient extraction than is obtained by keeping the sample continuously covered with ether. The extraction with ether is continued for about three-fourths of an hour for most explosives. This period is usually somewhat longer than is necessary to remove all of the nitroglycerin, but it is desirable to carry on the extraction long enough to insure the complete removal of material soluble in ether, so as to avoid testing for completeness of extraction. If for any reason a shorter time for extraction is desirable, the extraction is continued for the time desired, after which a small additional amount of ether is put into the apparatus, and the ether passing through the crucible is evaporated in a watch glass and an examination made for residue. If residue is found, complete extraction has obviously not been accomplished.

The crucible containing the portion of the explosive insoluble in ether is placed in a drying oven heated to about 100° C. This should be done promptly, since the evaporation of the ether with which the contents of the crucible are saturated lowers the temperature of the crucible sufficiently to cause the precipitation of considerable moisture upon the crucible and its contents, and such a precipitation is undesirable as it necessitates longer drying. Although no loss or inaccuracy in analysis is liable to result from the constituents of the explosives becoming wet at this stage, yet for uniform results in drying it is usually best to transfer the crucible directly from the Wiley extractor to the drying oven. To avoid filling the drying oven with ether vapors, it is convenient to have a suction flask and carbon tube near the Wiley extractor, and as soon as the ether extraction is completed the crucible, still very wet with ether, may be placed in the carbon tube and sucked dry, after which it is placed in the drying oven.

If the qualitative examination has indicated the presence of ammonium nitrate, the drying of the material insoluble in ether should be carried out at 70° C. instead of 100° C., because at 100° an appreciable loss of ammonium nitrate results whereas at 70° the loss is slight.

The periods of drying generally adopted are five hours at 95° to 100°, and overnight or 18 to 24 hours at 70° C. Even at the higher temperature no error results by drying overnight unless ammonium salts or other volatile ingredients are present. A shorter time than five hours is probably sufficient in most cases, but the five-hour period has been adopted to cover all cases and obviates any necessity of an additional check weighing.

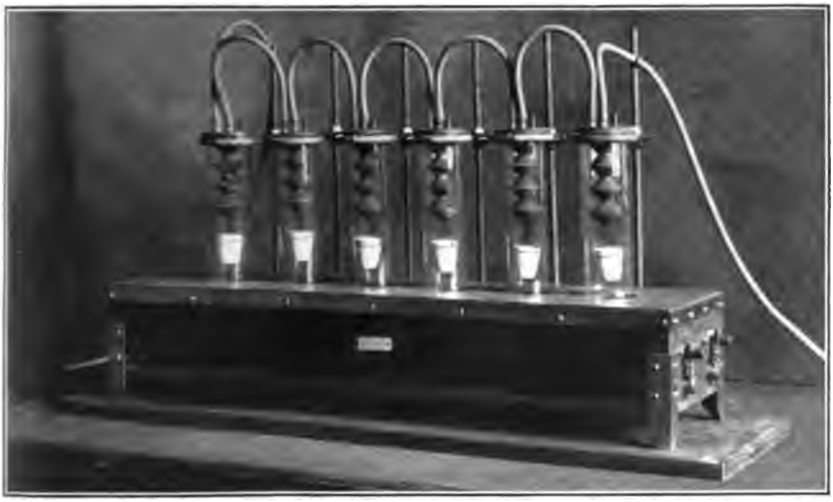
The loss of weight represents all ether-soluble material plus the moisture originally present in the sample.

The ether extract is transferred from the glass extraction tube to an evaporating dish of low pattern or to a small beaker previously weighed. The extraction tube is then washed out with a small quantity of pure ether, which is added to the ether extract in the evaporating dish. The contents of the evaporating dish are allowed to evaporate spontaneously; a number of hours are usually allowed for the evaporation, the best results being obtained when the period is overnight. After the ether has evaporated, the residue is thoroughly dried by leaving the dish for a few hours in a vacuum desiccator. The weight is then noted; it is usually a little less than the total loss on ether extraction minus the moisture as determined by desiccation. The difference is due to volatilization of the nitroglycerin during the evaporation of the ether, and is considered later.

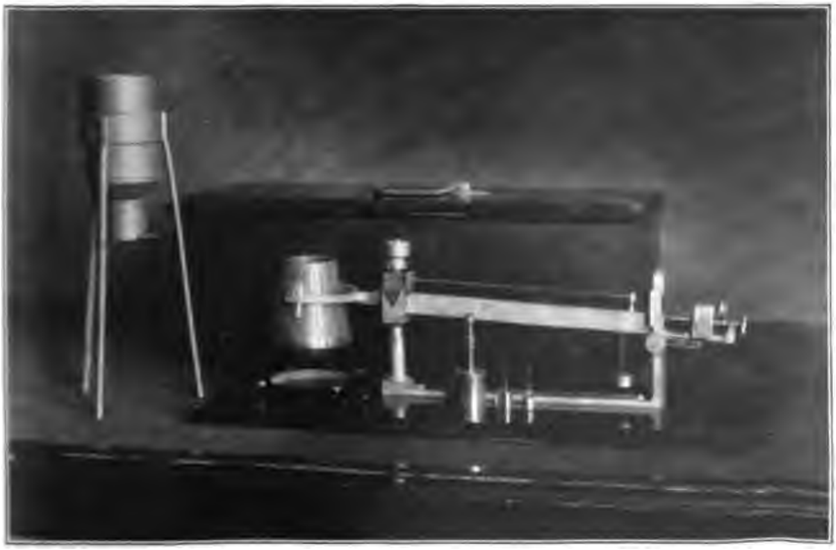
A more nearly correct value for the weight of material removed by ether is obtained by deducting the amount of moisture determined by desiccation from the total loss of weight found by extraction, the direct weight of the ether extract after the evaporation of ether being used only as a check. In all cases ether extraction should be made in duplicate, one sample of the weighed extract being used for the determination of the nitroglycerin with the nitrometer, and the other sample being used in determining the other constituents present.

SUCTION METHOD.

In the laboratories of some dynamite works extraction with ether is made without any form of continuous-extraction apparatus; the sample in the Gooch crucible is merely washed several times by pouring ether through it, applying suction after each addition of ether. This method involves the use of greater quantities of ether,



A. APPARATUS FOR ETHER EXTRACTION. WILEY EXTRACTOR.



B. GRAVIMETRIC BALANCE.

and the objection has been made that the reduction of temperature resulting from the evaporation of ether causes a deposition of moisture from the air current drawn through the sample, this moisture dissolving out small amounts of the water-soluble nitrates that pass through with the next addition of ether.

To test the merits of this method in comparison with the usual extraction method, ether extractions were made on a large number of samples of 45 per cent dynamite, using both the reflux-condenser method and the suction method. In the latter method about 100 c. c. of ether in six portions was passed through each sample, each portion of ether being allowed to stand in the crucible for one minute before suction was applied. The suction was continued for periods of one-half minute to two minutes in order that different amounts of air might be drawn through the samples. The samples were then dried and weighed as usual.

In general, extraction in the Wiley apparatus gave slightly lower results than the suction method, although in most cases the difference between duplicate samples extracted by the same method was as great as the variation between the two methods. This fact is explained by the lack of homogeneity of the dynamite. For example, a few unusually large particles of wood pulp or nitrate in one sample may cause a greater variation in the percentage of ether extract than the variation actually due to the method of extraction employed.

COMPARATIVE EXTRACTIONS WITH ANHYDROUS AND U. S. P. (96 PER CENT) ETHER.

To ascertain the effect of the purity of the ether used for extractions, determinations of ether extracts were made on several types of explosives, and on various carbonaceous absorbents used in dynamites. Duplicate determinations were made using both anhydrous ether (distilled over sodium) and U. S. P. (96 per cent) ether.

Results of extractions are shown in the following table, the values given being the percentage of loss of weight noted on weighing the insoluble portion after drying five hours at 95° to 100°. The loss of weight in each case therefore includes any moisture originally present.

Loss of weight of explosives and of carbonaceous absorbents by ether extraction.

Kind of sample.	Kind of ether.	
	U. S. P. (96 per cent).	Anhydrous.
	Per cent.	*Per cent.*
Dynamite (A)	25.86	25.69
Dynamite (B)	32.58	32.51
Dynamite (C)	40.77	40.74
Corn meal	14.81	14.92
Wheat flour	13.18	13.12
Wheat middlings	14.91	14.78
Corn meal, dry	1.81	1.71
Wood pulp, dry (1)	2.71	2.18
Wood pulp, dry (2)	2.59	2.20
Wood pulp, dry (3)	2.31	1.85
Wood pulp (4)	8.84	8.02
Wood pulp (5)	5.44	4.73
Wood pulp (6)	5.98	5.48
Wood pulp (7)	12.24	11.98
Wood pulp (8)	13.30	12.75
Wood pulp (9)	5.65	5.23
Wood pulp (10)	6.23	5.88
Wood pulp (11)	5.01	4.85
Wood pulp (12)	7.74	7.40
Wood pulp (13)	8.27	7.86

From the table it is apparent that U. S. P. ether extracts a larger percentage of material from the commonly used carbonaceous absorbents than does anhydrous ether, which is practically free from alcohol. It is probably because of the alcohol present, in amounts up to about 4 per cent, that U. S. P. ether shows the greater extractive power.

EFFECT OF MOISTURE IN DYNAMITE ON EXTRACTION WITH ETHER.

Numerous authorities prescribe that the ether extraction shall be made on a sample previously dried to constant weight in a desiccator.[a] Presumably this specification is aimed to prevent water-soluble constituents from being carried through in the ether extract. Such an error is naturally greater as the amount of moisture present in the dynamite is greater. Accordingly experiments were made on mining explosives similar to ordinary dynamite, to which water had been added as an additional constituent for the purpose of reducing the temperature of explosion. Two explosives containing 10.70 and 5.70 per cent of moisture, respectively, were extracted with ether in the usual manner, (1) in the original condition, and (2) after having been dried in vacuum desiccators over sulphuric acid for 24 hours. The amounts of materials soluble in ether extracted are shown in the following table.

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[a] Guttman, O., Schiess-und Sprengmittel, 1910, p. 162; Kedesdy, E., Sprengstoffe, 1909, p. 247; Escales, R., Die Explosivstoffe, vol. 3, 1908, p. 204.

Results of ether extraction of two explosives in different conditions.

1	2	3	4	5
Sample.	Condition.	Moisture.	Extract.	Difference.
		Per cent.	*Per cent.*	*Per cent.*
A	1	10.70	26.52	0.59
	2	.44	[a]25.93	
B	1	5.70	25.79	.36
	2	.45	[a]25.43	

[a] Calculated to explosive in original condition.

The amount of moisture present in the dried samples was found by desiccating portions of each sample for a further period of three days in ordinary sulphuric-acid desiccators.

The values in column 4 represent the total loss on extraction less the moisture content of the sample, all results being expressed as a percentage of the amount of original undried explosive.

Assuming that the extracts from the samples in their original condition (condition 1) are larger than those from the dried samples (condition 2) because of loss of water-soluble nitrate in the moisture taken up by the ether, it is apparent that in the case of ordinary dynamite containing only one or two per cent moisture any loss from this source is negligible.

DETERMINATION OF NITROGLYCERIN.

The nitrogen of organic or inorganic nitrates or nitrites is readily evolved as nitric oxide (NO) by reaction with sulphuric acid and mercury in the nitrometer. A determination of such nitrogen in the extract therefore serves as a means of calculating the amount of nitroglycerin present. The form of nitrometer found by the authors to be most satisfactory for explosives work is the modified Lunge nitrometer, as illustrated in Plate III.

THE NITROMETER.

This instrument[a] consists of six glass parts as follows: A globe-shaped reservoir (*a*); a generating bulb (*b*) of about 300 c. c. capacity, the generating bulb having stopcocks at both top and bottom to permit a violent agitation, and having a cup above which communicates with the bulb through the upper stopcock; a second globe-shaped reservoir (*c*), to which, by means of a glass multiple connecting tube and rubber tubing, are joined a compensating burette (*d*), a reading burette (*e*), and an additional measuring burette (*f*). The reading and compensating burettes are of the same shape and size, and are blown out into bulbs at the top. The compensating burette is not graduated. Above the bulb it has a small vertical open tube, which is sealed when the instrument is standardized. The reading burette is calibrated so that percentages of nitrogen may be read therefrom, and is marked to read from 10 to 14 per cent, being graduated to one-hundredths of 1 per cent. Between 171.8 and 240.4 c. c. of gas must be generated to obtain a reading; that is, the 10 per cent mark represents the volume of 171.8 c. c. of NO at 20° and 760 mm. pressure, containing 0.1 gram of nitrogen; the 14 per cent mark is equal to 240 c. c. NO under the same conditions, representing 0.14 gram nitrogen.

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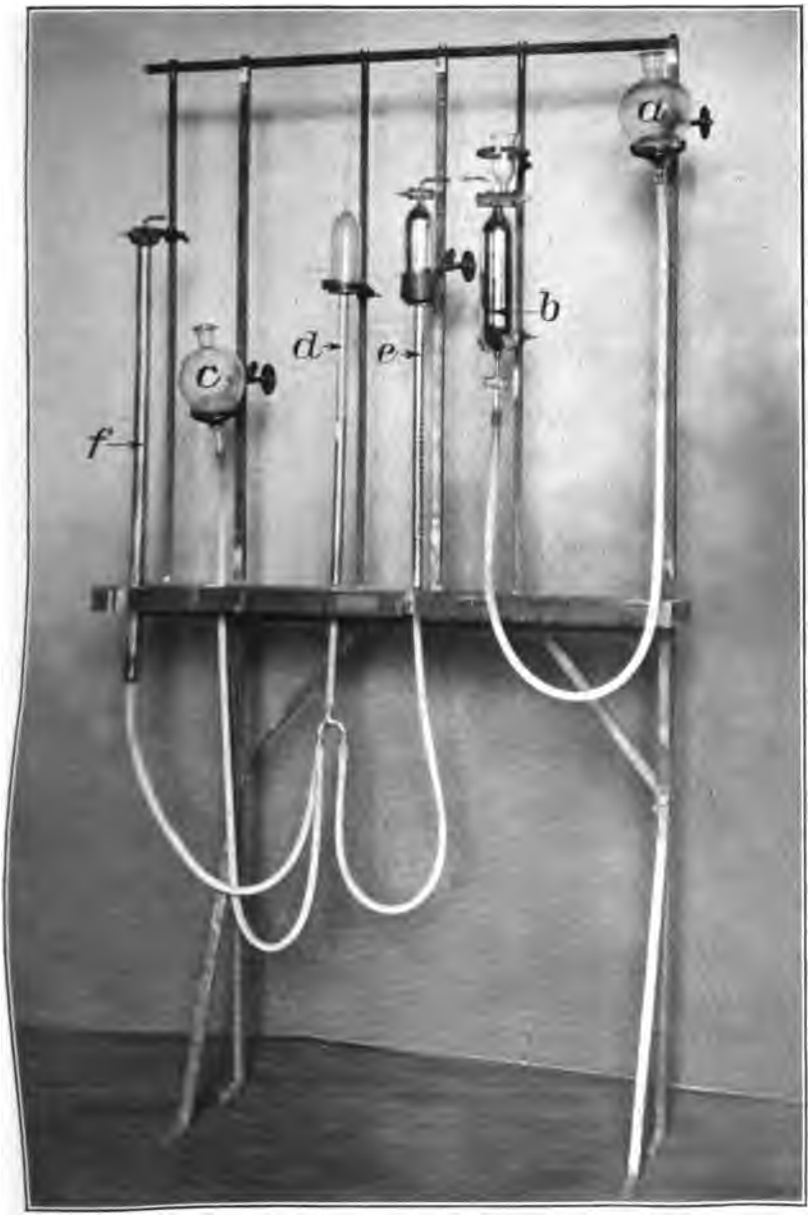
[a] The description has been taken in a large part from a paper by J. R. Pitman on The analysis of nitric and mixed acids by du Pont's modification of the Lunge nitrometer, Jour. Soc. Chem. Ind., vol. 19, 1900, p. 983; see also Lunge, G., Du Pont's nitrometer, Jour. Soc. Chem. Ind., vol. 20, 1901, p. 100.

The compensating burette is supported by a ring; the generating bulb is supported just above each stopcock by forked holders, curved so as to retain the bulb in place. In order to remove the generating bulb it needs only to be raised slightly and brought forward, the manipulation of a screw, as with an ordinary clamp, being thus avoided. The two reservoirs and the reading burette are supported by ring clamps, these clamps having milled rollers at the shank; they are moved up and down vertical racks by means of hand screws, the rollers being so arranged in conjunction with the vertical racks that the weight of the part presses them down and acts as a brake, thus preventing their moving when not being manipulated.

Having arranged the apparatus and filled the compensating, reading, and generating tubes as well as their connections with mercury, the next step is to standardize the instrument. Twenty to thirty cubic centimeters of sulphuric acid is run into the generating bulb through the cup at the top, and at the same time about 210 c. c. of air is let in; the cocks are then closed and the bulb is well shaken; this shaking thoroughly desiccates the air, which is then run into the compensating burette until the murcury is about on a level with the 12.50 per cent mark on the reading burette, the two burettes being held at the same height. The compensating burette is then sealed off at the top. A further quantity of air is desiccated in the same manner and run over into the reading burette until the height of mercury in the reading burette stands at about the 12.50 per cent mark. The cocks are then closed, and a small piece of glass tubing, filled with sulphuric acid (not water), and bent in the form of a U, is attached to the outlet of the reading burette. When the mercury columns are about balanced and the inclosed air has been cooled to room temperature, the cock is again carefully opened, and when the sulphuric acid balances in the U tube, and the mercury columns in both burettes are therefore at the same level, the air in each tube is subject to the same conditions, namely, atmospheric temperature and pressure. A reading is now made from the burette,



NITROMETER.

and the barometric pressure and temperature are carefully noted. Using the well-known formula

$$V=\frac{V'P'(273+t)(1-.00018t')}{P(273+t')(1-.00018t)}$$

the volume this inclosed air would occupy at a pressure (P) of 29.92 inches of mercury (760 mm.) and at a temperature (t) of 20° C. is determined. The cock is again closed and the reservoir and reading burette carefully adjusted so as to bring the air in the reading burette to the calculated volume and the mercury in the compensating burette to the same level as the mercury in the reading burette. A strip of paper is now pasted on the compensating burette at the level of the mercury, and the standardization is then complete.

There is, however, another and shorter method of standardization than the one described above. It is well known that the quality of the sulphuric acid used in the nitrometer will materially affect the results. To ascertain whether sulphuric acid is suitable for use in making nitrogen determinations in the nitrometer a determination is made on chemically pure dry potassium nitrate and the reading obtained in the nitrometer is compared with the theoretical percentage of nitrogen in potassium nitrate. In applying this procedure to the standardization of the nitrometer the compensating burette is filled with desiccated air, as described above, and 1 gram of potassium nitrate, dissolved in 2 to 4 c. c. of water, is introduced into the generating bulb, the cup is washed with 20 c. c. of 95 to 96 per cent sulphuric acid in three or four portions, and each portion is run separately into the bulb. The gas, when generated, is run over into the reading burette, and the mercury columns in both burettes are leveled, so that the mercury in the reading burette is also at 13.87, the theoretical percentage of nitrogen in potassium nitrate. A strip of paper is pasted on the compensating burette at the level of the mercury, and the standardization is then accomplished.

This method of standardizing offers many advantages over that first described, among which may be mentioned that no readings of temperature or pressure are necessary. Probably the greatest advantage is that if the acid used in standardizing should contain impurities, which might otherwise affect the result, the error is entirely compensated and corrected in subsequent work; that is to say, the instrument having been so standardized that the reading gives the theoretical percentage of nitrogen in potassium nitrate, the results will be accurate when testing other substances so long as the same quantity of sulphuric acid from the same lot is used.

It must, of course, be understood that once having standardized the instrument with a certain lot of acid no different lot of acid can be used without restandardizing. In order to avoid slight differences in results due to variations in the acid, it is advisable to reserve a sufficiently large uniform stock of acid, for example, a carboy full, for nitrometer use.

The additional measuring burette, with which this type of nitrometer is provided, known as the "universal tube" (*f*, Pl. III), is simply a straight burette, marked to read from 0 to 100 in percentages and graduated to one-tenth of 1 per cent. The tube is of such a size that 0.30 gram of NO (or $\frac{1}{100}$ gram-molecule of NO) under standard conditions of temperature and pressure (20° and 760 mm.) fills it to the 100 mark.

If it is desired to read the percentage of nitrogen direct, 0.14 gram of substance is weighed out; if the percentage of NO_2 is desired, 0.46 gram of substance is weighed out. Consequently, if 1.01 grams of potassium nitrate, 0.63 gram of nitric acid, or 0.85 gram of sodium nitrate are used, the results can be read directly as percentages of the original substance.

This method is convenient when it is not certain that the reading will fall within the limits of the graduations in the ordinary measuring burette.

The "universal tube" is found particularly advantageous when, for example, the amount of nitroglycerin in a sample is so small that the volume of gas generated is insufficient to fill the large reading burette to its graduated portion. The volume of gas generated from any amount of nitroglycerin up to about 0.75 gram may be read in the "universal tube." Readings in this measuring tube can be as accurately made as in the regular reading burette.

PROCEDURE.

To determine the amount of nitroglycerin in the ether extract of a dynamite, the sample from which the ether has been evaporated is dissolved in 5 to 10 c. c. of sulphuric acid (specific gravity, 1.84) and transferred to the generating bulb of the nitrometer, the beaker and the cup of the nitrometer being rinsed with several further additions of acid until 20 to 25 c. c. has been used. If the quantity of nitroglycerin present is too great, the sample dissolved in sulphuric acid is transferred to a burette and an aliquot part run into the nitrometer cup and washed into the generator with about 20 to 25 c. c. of sulphuric acid. The maximum amount of pure nitroglycerin used should be not greater than 0.75 gram in order that the gas generated will not exceed the volume of the reading burette.

The generator is then shaken gently until the generation of gas has forced out all but about 60 to 75 c. c. of the mercury, the reservoir being lowered if necessary in order to reduce the amount of mercury to this extent. The cock at the bottom of the generator is then closed and the generator shaken violently for about two to three minutes. After allowing all bubbles to separate from the reaction mixture, the gas is transferred to the reading burette, the surface of the mercury in the burette is brought to the same level as that in the compensating burette when the dry air in the compensating burette occupies the standard volume indicated by the strip of paper attached in calibrating.

The gas is allowed to stand for a few minutes to obtain an equilibrium of temperature, the levels being readjusted if necessary, and the reading is noted. This reading divided by 18.50 equals the weight of nitroglycerin in the sample used for the determination.

A more or less serious error to be considered in the determination of nitroglycerin is that introduced by losses due to volatilization of the nitroglycerin during the evaporation of the ether. To determine the effect of the rapidity of evaporation on the amount of nitroglycerin lost, weighed samples (0.6 to 0.7 gram) of nitroglycerin were placed in 100 c. c. beakers, treated with 50 c. c. of ether, the ether evaporated at different rates, and the samples dried in vacuum desiccators to remove the moisture taken up during the evaporation of the ether. Nitrogen was then determined by means of the nitrometer, the weight of nitroglycerin being calculated from the nitrometer reading. The results obtained are tabulated below:

Loss of nitroglycerin on evaporating ether extract.

[Determinations by J. H. Hunter.]

1	2	3	4	5	6	7
Sample.	Original weight of sample.	Weight of residue after evaporation of ether.	Nitrometer reading.	Weight of nitroglycerin found by nitrometer.[a]	Loss of nitroglycerin (2–5).	Method of evaporation.
	Gram.	*Gram.*	*Per cent.*	*Gram.*	*Gram.*	
1	0.6469	0.6458	11.78	0.6389	0.0080	At room temperature overnight.
2	.6328	.6318	11.53	.6280	.0048	Do.
3	.6212	.6140	11.17	.6084	.0128	Gentle boiling.
4	.6643	.6375	....	....	[b] .0268	Do.
5	.6199	.6167	11.81	.6160	.0039	Do.
6	.6666	.6660	11.96	.6514	.0152	Current of compressed air blown over beaker.
7	.6773	.6710	12.10	.6590	.0183	Do.

[a] Weight of nitroglycerin = nitrometer reading + 18.50.

[b] Loss of weight.

No attempt was made to obtain constant weight after evaporation of the ether, the samples being left in vacuum desiccators only long enough to remove most of the water; hence the weights in column 3 are greater than the weights of nitroglycerin calculated from the nitrogen found (column 5).

The figures in column 6 represent the differences between the weights in columns 2 and 5.

It was noted that rapid removal of the ether, either by means of gentle heating or by means of an air current, caused a greater loss of nitroglycerin than did slow spontaneous evaporation at room temperature, the only exception being in the case of sample 5, with which the loss of nitroglycerin was only 0.0039 gram, the ether being volatilized by gentle boiling. The large loss noted with sample 4 was probably due to spurting.

Such losses as are shown in the table do not greatly affect the determination of nitroglycerin in a sample of dynamite. Thus, in analyzing a 6-gram sample of dynamite, a loss of 0.01 gram of nitroglycerin would be equivalent to only 0.17 per cent of the original sample. The importance of the error is of course greater as the percentage of nitroglycerin in the sample is less.

Evaporation in the bell-jar evaporator.—An improved method of removing the ether from the ether extract without appreciable loss of nitroglycerin was devised by A. L. Hyde in the bureau's laboratory. The beaker containing the ether solution is placed on a ground-glass plate and covered by a glass bell jar about 6 inches in diameter and 8 inches high, having two tubulures, one at the top and one on the side, each opening being fitted with a perforated stopper and delivery tube. A rapid current of compressed air, dried by passage through concentrated sulphuric acid, in two wash cylinders, is allowed to enter through the glass tube in the top of the bell jar, the lower end of the tube being about one-half inch above the surface of the ether solution in the beaker. The air current is so regulated that a marked "dimple" is made in the surface of the solution, care being taken to prevent any loss by spattering. The possibility of acid being mechanically carried over from the cylinders is avoided by connecting an empty trap between the cylinders and the bell jar. The ether vapors pass out through the glass tube in the side tubulure and may be conducted out of the laboratory through a rubber tube passing to a hood or out of a window.

The low temperature produced by the rapid evaporation of the ether minimizes the volatilization of the nitroglycerin, and the fact that the air is thoroughly dried prevents any deposition of moisture in the beaker, so that it is not necessary to desiccate the residue after the ether has entirely volatilized.

The following preliminary tests show the efficiency of the method: A weighed quantity of nitroglycerin was dissolved in 50 c. c. of ether, the ether evaporated as described, and the residue in the beaker weighed at intervals.

Loss of nitroglycerin by evaporation of ether solution in bell-jar evaporator.

Time of evaporation.	Weight of sample.			
	A	B	C	D
Hours.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
0	[a] 2.838	[a] 3.236	[a] 2.979	[a] 2.620
2	3.176	3.359	3.189	2.801
3	2.941	3.286		
4	2.881	3.262	3.037	2.644
5	2.863	3.251		
6	2.856	3.245	2.987	2.623
7	2.851	3.241	2.984	2.621
9	2.843	3.236	2.978	2.619
11	2.841	3.235	2.977	2.618
14	2.837	3.234		

[a] Original weight of nitroglycerin.

U. S. P. ether (96 per cent) was used in tests A and B, and alcohol-free ether (distilled over sodium) in tests C and D. When the 96 per cent ether was used a distinct odor of acetic aldehyde was noticed and the rate of loss of weight was slightly lower, due no doubt to the presence of alcohol in the ether.

It is apparent from the above results that this method offers a convenient and rapid method of removing the ether without appreciable loss of nitroglycerin. Evaporation for about six hours removes the ether sufficiently to permit determination of the nitroglycerin in the nitrometer.

DETERMINATIONS OF SULPHUR, RESINS, ETC.

The sulphur used in dynamite is the form known as crushed brimstone. It is soluble in about 100 parts of ether at 23.5° C.,[a] and unless present in large amount in the sample of explosive being analyzed it will all be removed by the extraction with ether. However, when a considerable amount of sulphur crystallizes out in the ether extract, it is always advisable, after the water extraction, to make a further extraction of the explosive with carbon disulphide, in order to insure the complete removal of the sulphur.

As already mentioned, the analysis of an explosive is carried out in duplicate, one sample of the ether extract being used for the determination of nitroglycerin, the duplicate sample being used for the determination of sulphur, resins, etc. The duplicate sample is treated as follows: The weighed extract is redissolved in a mixture of ether and alcohol previously neutralized with standard alkali. The solution thus obtained is titrated with standard alcoholic potash to determine resins, phenolphthalein being used as an indicator. Determinations of a number of samples of commercial rosin (colophony) gave rather uniform results, 1 c. c. of normal alkali being found equal to 0.34 gram of rosin, which agrees with the value given by Lewkowitsch.[a]

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 85.

After titration a large excess of alcoholic potash is added and the mixture is heated on the steam bath, preferably overnight, in order to saponify the nitroglycerin. It must be remembered that nitroglycerin so treated saponifies slowly. Hence the reaction must not be hastened by heating to a higher degree than that obtained on a water bath, as an explosion may result. When saponification is complete the residue left upon evaporation is shaken with water and ether and separated in a separatory funnel. Any oily material (vaseline, paraffins, etc.) that can not be saponified is dissolved in the ether and may be weighed after evaporation. The water solution is acidified with hydrochloric acid and treated with bromine to oxidize the sulphur. Any rosin that was originally present will have formed a soap with the alkali; the acid decomposes this soap, and the rosin separates out from the acid liquid, floats on it, and may be readily removed, dried, and weighed, the weight serving as a check on the results of titration. The sulphur is oxidized to sulphuric acid by the bromine and may be determined by precipitation as barium sulphate.

Sulphur may be separated from nitroglycerin by a method depending on the fact that nitroglycerin is soluble in 70 per cent acetic acid, whereas sulphur dissolves only slightly in either glacial or 70 per cent acetic acid. The extent to which sulphur dissolves in acetic acid was determined by experiments with both brimstone and flowers of sulphur, in both cases the material being pulverized so as to pass through an 80-mesh sieve.

One gram of sulphur was digested in 100 c.c. of acetic acid for a definite period of time; the mixture was then washed on to a weighed Gooch crucible, dried for five hours at 70°, and weighed. The loss in weight represented the amount of sulphur dissolved by 100 c. c. of acid. The results were as follows:

Solubility of sulphur in acetic acid.

[Determinations by J. H. Hunter.]

Form of sulphur.	100 c. c. of 70 per cent acetic acid.			100 c. c. of glacial acetic acid.		
	Temperature.	Time.	Weight of sulphur dissolved.	Temperature.	Time.	Weight of sulphur dissolved.
	° C.	*Hours.*	*Gram.*	*° C.*	*Hours.*	*Gram.*
Brimstone	25	1	0.000	25	1	0.0338
	25	25	.000	25	1	.0354
	80	1	.0226	80	1	.1658
	80	1	.0127	80	1	.1464
Flowers of sulphur	25	20	.0115	....	....	....
	25	20	.0090	....	....	....
	80	1	.0027	....	....	....
	80	1	.0036	....	....	....

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[a] Lewkowitsch, J., Chemical technology and analysis of oils, fats, and waxes, vol. 1, 1909, p. 502.

These determinations show that sulphur (brimstone) can be separated from nitroglycerin by means of acetic acid (70 per cent) at ordinary room temperature without appreciable loss of the sulphur.

EXTRACTION WITH WATER.

The determination of water-soluble constituents is made on the dried and weighed residues left in the crucibles after extraction with ether. The apparatus used consists of an ordinary heavy-walled side-neck suction flask provided with a rubber stopper, through which passes a carbon filter tube. The crucible is inserted in the top of the filter tube, a tight joint being obtained by means of a short length of thin-walled rubber tubing. As the analysis is made in duplicate, two suction flasks so arranged are connected to a Y tube, and both samples are extracted at once. A Bunsen valve or an empty bottle to serve as a trap should be inserted between the Y tube and the suction pump to guard against any tendency of the water to "suck back."

Cold water is used for the extraction because hot water would partly gelatinize any starch that might be present, and hot water would also remove more soluble organic material from the wood pulp. The water is passed through each sample in small quantities (about 20 c. c.) at a time. The sample is covered with water, allowed to stand a short time, and suction applied until all the water has passed into the flask. This process is repeated until at least 200 c. c. of water has been used. If each portion of water is allowed to stand on the sample for a short time and then thoroughly sucked out, this quantity of water is more than sufficient for complete extraction, but in case of doubt a few drops of the last portions of the filtrate is tested by evaporation on a glass plate.

If starch is present the filtration often proceeds very slowly because of the tendency of the starch to separate at the bottom of the crucible and form an almost impermeable layer on top of the asbestos mat. In such cases the use of stronger suction simply increases the density of this mass and retards rather than aids filtration. When any considerable quantity of starch has been detected in the qualitative examination, it is advisable to make use of porous alundum crucibles for the analysis, since these allow the filtrate to pass through the walls above the dense material at the bottom. With these crucibles it is necessary to use carbon tubes of such diameter that the crucible projects the greater part of its depth into the tube, being held by the rubber about one-fourth inch from its top. If this is not done there is a tendency for the filtrate to leak out of the crucible above the rubber.

These porous crucibles have been found decidedly convenient, especially in the case of materials that tend to clog the ordinary Gooch crucible.

The water extraction having been completed, the crucibles, with their contents, are again placed in the drying oven and dried for five hours at about 95 to 100° C. No additional loss results from longer drying at this temperature, and frequently to save time samples are dried overnight. After cooling in a desiccator the crucibles are weighed and the loss of weight noted. This loss of weight represents the total water-soluble material, and, in addition to the water-soluble salts detected in the qualitative examination, includes organic extract from the wood pulp, flour, or other absorbent. When cereal products are present the amount of organic material thus extracted may amount to 2 per cent or more, including sugars, etc., that form constituent parts of the grain. Frequently the antacid used, generally calcium carbonate or magnesium carbonate, is attacked by acid decomposition products from the nitroglycerin, a portion of the carbonate being thereby converted to nitrate or nitrite. In such cases some calcium or magnesium is found in the water extract.

Usually the only water-soluble constituent to be considered in an ordinary dynamite is an alkaline (sodium or potassium) nitrate. When an approximate analysis only is desired it is generally considered sufficient to regard the total loss of weight on extraction as nitrate, but, as shown above, this frequently gives erroneous results.

DETERMINATION OF ALKALINE NITRATES.

The method best suited for determination of nitrates is the following: An aliquot portion of the water extract is evaporated to dryness on a water bath and the residue gently ignited to burn off the organic matter. After cooling, the sides of the evaporating dish are washed down with a few cubic centimeters of water, about 1 c. c. of nitric acid is added, the evaporation repeated, and the residue heated gently over a burner until just fused, or the residue is dried in an oven at about 120° C. The treatment with nitric acid is necessary for the complete conversion to nitrate of any nitrite resulting from burning off the organic matter. The treatment should be repeated until the weight of the residue is constant.

The weighed residue is calculated as percentage of nitrate in the original explosive. Since this weight necessarily includes any nonvolatile water-soluble impurities originally present in the nitrate, as iron, aluminum, chlorides, sulphates, etc., for an exact analysis it is necessary to ascertain the amount of such impurities by volumetric or gravimetric determinations on fresh aliquot portions of the water extract, or a direct determination of the true nitrate content may be made in the nitrometer as described on the following page.

DETERMINATION OF ALKALINE NITRATES BY MEANS OF THE NITROMETER.

An aliquot portion of the water extract estimated to contain the proper amount of nitrate for determination in the nitrometer (about 0.6 to 0.8 gram of $NaNO_3$ or 0.8 to 1.0 gram of KNO_3 for the type of nitrometer previously described, p. 35) is evaporated almost to dryness on a steam bath and transferred, by means of as little water as possible, to the cup of the nitrometer. The amount of water used should not exceed 20 c. c. This solution is drawn into the generator, and 30 to 40 c. c. of sulphuric acid (95 to 96 per cent) is added slowly, in small quantities at first to avoid generating sufficient heat to crack the glass. Because of the dilution of the acid the generation of the gas proceeds much more slowly than in the determination of nitroglycerin, and it is necessary to shake the generator for a total time of about 8 to 10 minutes in order to be certain that the reaction is complete. The volume of gas is measured and the percentage of nitrate is calculated in the same manner as in the case of nitroglycerin. This method is excellent for use as a check or for an exact determination of the actual nitrate content.

Tests made on a 1 per cent solution of pure potassium nitrate by both the gravimetric and volumetric methods described above gave results as follows:

Results of determinations of nitrates in a water solution by the gravimetric and by the volumetric method.

[Determinations by J. H. Hunter.]

Test No.	Volume of solution used.	Weight of KNO_3 used.	Gravimetric method.	Volumetric method.	
			Weight of KNO_3 found.	Reading of nitrometer (N).	Weight of KNO_3 found.
	c. c.	*Grams.*	*Grams.*		*Grams.*
1	100	1.0000	0.9994	....	....
2	100	1.0000	....	13.92	1.0036
3	100	[a] 1.0000	.9997	....	....
4	100	[a] 1.0000	....	13.92	1.0036
5	100	[b] 1.0000	1.0004	....	....
6	100	[b] 1.0000	....	13.93	1.0043

[a] Two one-hundredths gram of sugar was added to the 100 c. c. of nitrate solution.

[b] Two one-hundredths gram of sodium chloride was added to the 100 c. c. of nitrate solution.

EXTRACTION WITH ACID.

As already pointed out, the materials most commonly used as antacids are the carbonates of calcium or magnesium or the oxide of zinc. Frequently ground dolomite is used, in which case both calcium and magnesium must be determined. The qualitative examination will have shown, however, what acid-soluble materials are present.

The procedure to be followed in making the acid extraction depends on whether or not starch is present in the explosive. In either case the dried and weighed residue insoluble in water is used for the treatment with acid.

In the absence of starch a simple extraction is made with cold dilute hydrochloric acid (1:10), 100 c. c. being drawn through the sample in the crucible in small successive portions, as described under "Extraction with water" (p. 43). Several portions of water are then drawn through to wash out the acid, and the crucible with the insoluble residue is dried as before for five hours at 95 to 100° C. It is sufficiently accurate to use this "loss-of-weight" figure as the amount of antacid, as the amount of organic material extracted from the wood pulp will be very small, but if greater accuracy is desired a quantitative determination of the dissolved base or bases may be made by the usual gravimetric methods

DETERMINATION OF CALCIUM.

Calcium is determined as follows: An excess of ammonium hydroxide is added and the solution boiled. Any precipitate of iron or aluminum hydroxides may be filtered off, ignited, and weighed, but the amount of such impurities is usually so small that it may be disregarded and calcium precipitated without previous filtration. Hot ammonium-oxalate solution is added in slight excess to the boiling solution and the boiling is continued for a short time. The precipitate is allowed to settle completely, and then is filtered, dried, and weighed as CaC_2O_4, or is ignited and weighed as CaO.

DETERMINATION OF MAGNESIUM.

Magnesium is determined in the filtrate from the calcium determination by concentrating to about 100 c. c., adding an excess of a solution of sodium hydrogen phosphate to the hot solution, then a large excess of ammonium hydroxide, and allowing the phosphate precipitate to separate completely by standing for several hours. The precipitate is filtered in a Gooch crucible, washed, ignited, and weighed as $Mg_2P_2O_7$.

DETERMINATION OF ZINC.

Zinc is precipitated with Na_2CO_3 solution as carbonate, ignited, and weighed as ZnO. If ammonium salts are present the zinc is precipitated with H_2S as ZnS, the ZnS filtered off, redissolved, and precipitated as carbonate. The determination of zinc is more fully considered in the discussion of ammonia dynamites on page 58.

DETERMINATION OF STARCH.

When starch is present both the starch and the antacid are removed in one operation by boiling with dilute acid, whereby the starch is rendered soluble by conversion to dextrin. In carrying out this process the material in the crucible is moistened with water and completely transferred with a spatula, or by washing with a stream of water from a wash bottle, into a beaker of about 500 c. c. capacity. If a Gooch crucible is used the asbestos is removed with the residue and the clean crucible dried and weighed. From the original weight of the crucible plus the asbestos the weight of the asbestos is ascertained and deducted from the final weight of dried residue remaining after hydrolysis. The volume of water in the beaker is made up to about 250 c. c., and about 3 c. c. hydrochloric acid (specific gravity 1.2) is added, and the mixture is stirred and brought to boiling over a burner. Boiling is continued until the starch is entirely hydrolized, a drop of the acid mixture being tested from time to time on a spot plate with a solution of iodine in potassium iodide until a blue coloration is no longer obtained. Longer boiling will only result in loss of extractive material from the wood pulp.

The boiled material is then at once filtered through a fresh crucible or through the original porous crucible, if such was used, washed several times with water, dried as before, and weighed. If the figures representing the weight include the weight of the asbestos mat from a Gooch crucible, the proper correction for the weight of the asbestos is made as noted above.

The amount of antacid contained in the acid filtrate is ascertained by a gravimetric determination as previously described.

It has already been noted (p. 44) that small amounts of soluble organic material (sugars, dextrin, etc.) from flour or other cereal products and extract from the wood pulp will be found in the water solution. In summarizing the results of analysis it is of course impossible to know what portion of such extracted organic material constituted part of the flour and what portion should properly be added to the wood pulp. Similarly, the organic material dissolved during the acid hydrolysis includes not only such portions of the grain as starch and gluten but soluble portions of the wood pulp.

It is customary in quoting the results of analysis to include all such soluble organic material from both water and acid extractions under the term "starch," and the insoluble residue is designated as "wood pulp and crude fiber." In other words, the weight of insoluble residue dried at 100° is called "wood pulp and crude fiber," whereas the sum of this constituent and of the ingredients determined in the ether, water, and acid solutions, deducted from the weight of original sample, is called "starch."

In the case of a dynamite which contains no cereal product, the sum of the determined ingredients deducted from the weight of original sample is taken as the amount of wood pulp present and includes the material extracted from the pulp by the water and acid treatment as well as the insoluble residue found by direct weight.

The actual amounts of wood pulp and of cereal products added in manufacture can not therefore be definitely determined, since portions of each will be found in the ether, the water, and the acid extractions as well as in the insoluble residue.

In order to determine to what extent the wood pulp in a dynamite is affected by the various extractions, etc., necessary in the course of analysis of the dynamite, dried samples of various grades of pulp were submitted to the treatment through which the insoluble wood pulp residue in a sample of dynamite had passed.

Samples of 2 to 3 grams of wood pulp were weighed in Gooch crucibles, dried to constant weight, and extracted successively with ether, water, and cold hydrochloric acid (1:10), and then boiled for 15 minutes with dilute hydrochloric acid (1:100). The latter treatment would be necessary if starch were present with the wood pulp in an explosive. After each operation the sample was dried five hours at 100°, and the loss of weight was determined. The results were as follows:

Results of analyses of wood pulp.

Sample No.	Loss of weight (per cent of dry sample.)				Percentage of insoluble residue.
	Extraction with ether.	Extraction with cold water.	Extraction with cold HCl(1:10).	Boiling with HCl (1:100)	
1.......	2.66	2.57	1.41	5.91	87.45
2.......	2.78	2.89	.42	1.75	92.16
3.......	2.09	2.23	.53	3.93	91.22
4.......	1.95	2.84	1.03	4.83	89.35

These experiments show that the final insoluble residue that is weighed as wood pulp may be only about 90 per cent of the amount of dry wood pulp actually present in the dynamite. A part of the loss is determined as rosin in the ether extract, and the portions extracted with water and hot acid are calculated as starch (if starch has been determined). When starch is not present the error in the determination of pulp is much less as the boiling-acid treatment is dispensed with. The analysis can then be made accurate by direct determination of the water-soluble nitrate and of the antacid as described above, and the amount of wood pulp can be found by subtracting the sum of the percentages of moisture, nitroglycerin, alkaline nitrate, and antacid from 100 per cent. This amount will be in excess of the percentage of insoluble residue found, according to the amounts of pulp extracted by the water and acid.

EXAMINATION OF INSOLUBLE RESIDUE.

DETERMINATION OF WOOD PULP, ETC.

The residue that remains after the ether extraction, the water extraction, and the extraction with dilute acid is usually a mixture of wood pulp, sawdust, or other form of cellulose or lignin. When corn meal, flour, middlings, bran, etc., are present in the dynamite, the residue will contain the nonstarchy portions of these materials, either free or mixed with wood pulp. In general, ordinary dynamite contains wood pulp alone as the absorbent, but low-freezing dynamites and "straight'' dynamites containing less than 40 per cent of nitroglycerin often contain considerable quantities of corn meal, wheat middlings, or low-grade flour.

Infusorial earth was formerly much used as an absorbent for nitroglycerin, but in recent years it has seldom been so used in this country, having been almost entirely replaced by an active base or dope.

If the hydrochloric acid has not been thoroughly washed from the insoluble residue, the wood pulp will considerably darken in color during the drying process. From its physical structure, as observed without magnification, or with a small lens, much information may be gained in regard to the probable composition of the insoluble residue, but in all cases the examination is best made under the microscope, with a low-power objective, one of 32-mm. focus being suitable. One of the duplicate samples of insoluble residue is used for microscopic and chemical examination, and one for the determination of ash. A small amount of the sample which is to be used for microscopic and chemical examination is removed from the crucible, placed upon a microscope slide, and moistened with one or two drops of water. By means of a platinum needle the material is then carefully spread out, but no cover glass is used. Wood pulp, the most common constituent in the residue of ordinary dynamite, will be seen as separate fibers or bunches of fibers of very characteristic appearance.

In Plate IV, *A* and *B*, wood pulp of different grades is illustrated, and the characteristic appearance of sawdust or dust from certain types of woodworking machinery is shown in Plate IV, *C*. The bundles or clusters of fibers are characteristic of such materials. Typical samples of infusorial earth (kieselguhr) are shown in Plate IV, *D* and *E*. It should be noted that, as plainly shown in the figures, widely differing types of infusorial earth exist, forms of organisms appearing in one sample which will not be found in another. The general appearance of shell remains is a definite indication of the presence of diatomaceous or infusorial earth. The sample shown in Plate IV, *D*, was obtained, through the courtesy of Dr. G. P.

Merrill, from the National Museum, Washington, D. C. (Specimen No. 6555, from Cornwallis, Nova Scotia.)

The appearance of the "husks" or crude fiber from coarse wheat flour (middlings), after hydrolysis of the starch, is shown in Plate IV, *F;* the cellular structure of the irregularly shaped particles of fiber is readily seen.

A and *B*, Plate V, represent cellulose (cotton) and nitrocellulose, respectively. These two materials can not be distinguished from each other by microscopic examination in ordinary light, but in polarized light a decided difference is noted, the unnitrated fibers appearing in brilliant colors and the nitrated fibers dark.

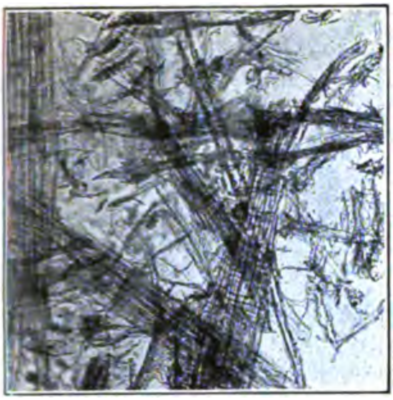
In the case of the presence of cereal products it is often of value to make a microscopic examination of the residue insoluble in water before hydrolysis of the starch. In Plate V, *C*, *D*, and *E*, such materials are shown. *C* represents ordinary fine wheat flour; *D*, wheat flour mixed with wood pulp; *E*, coarse wheat flour or middlings; and *F*, corn meal. Characteristic differences in the appearance of the starch granules of wheat and corn are of aid in identifying these cereals, the wheat starch granules being in general well rounded or oval, whereas the cornstarch granules are almost always distinctly polygonal in shape.

DETERMINATION OF ASH.

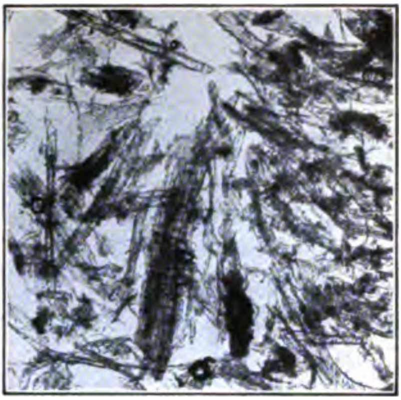
The remaining sample of residue from acid extraction is used for the determination of ash, and may be either incinerated in the crucible that has been used for extraction, or the residue, together with the asbestos mat, may be removed to a platinum crucible and ignited; in this case there is subtracted from the ash the known weight of asbestos present in the mat. The ash of an ordinary dynamite, containing only wood pulp, sawdust, or corn meal as absorbents, will seldom amount to more than 0.20 per cent. When the amount of ash present is as much as 0.5 per cent the ash should in all cases be examined under the microscope to determine the possible presence of infusorial earth or other inorganic material (pulverized glass, sand, etc.), provided the presence of these materials has not already been detected by the microscopic examination. A high ash content may also indicate that either the water or acid extractions have not been complete. In this respect the ash determination may be regarded as a check on the analysis.

VARIATIONS DUE TO METHOD OF ANALYSIS.

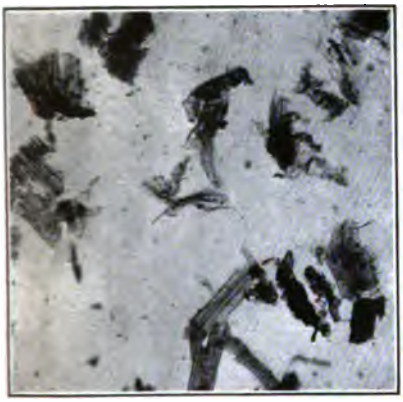
In order to ascertain to what extent the results of analysis of a dynamite would be effected by variations in the method of analysis, uniform samples of a 45 per cent dynamite were submitted to the laboratories of 11 explosives works, with the request that analyses be



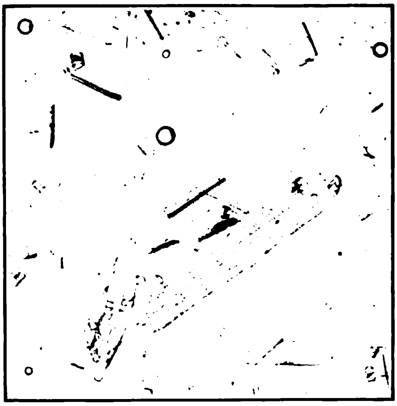
A. WOOD PULP NO. 1 (X 50).



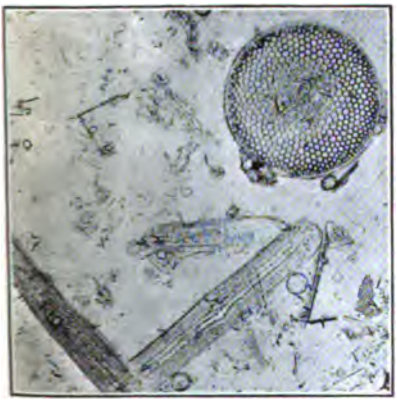
B. WOOD PULP NO. 2 (X 50).



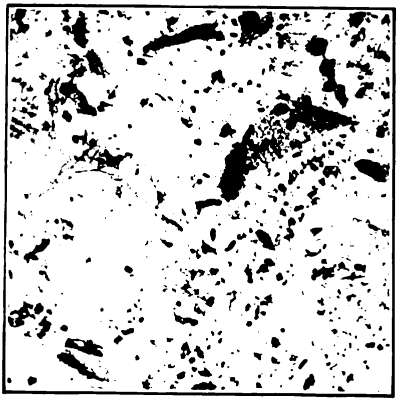
C. SAWDUST (X 25).



D. INFUSORIAL EARTH NO. 1 (X 150).



E. INFUSORIAL EARTH NO. 2 (X 150).



F. CRUDE FIBER FROM WHEAT MIDDLINGS (X 25)

made by the methods regularly in use in each laboratory and results reported, together with brief notes as to the method used.

The samples were prepared as follows: Fifty cartridges of a lot of 45 per cent dynamite were opened, about two-thirds of each cartridge removed (the ends being rejected), and broken up finely in a porcelain dish by means of a horn spoon. All of these portions were then mixed together very thoroughly in a large porcelain dish. From this uniform mixture about 20 sample bottles (150 c. c. capacity) were filled, the contents of each bottle then being emptied out separately into a dish, carefully mixed again, and replaced in the bottle. Each sample represented about 150 grams.

Eleven of these samples were sent to different laboratories, as noted above, and seven of them analyzed in the bureau's explosives chemical laboratory by different analysts. Careful instructions were sent with each sample, that, in order to compensate for any segregation occurring in shipment, the entire sample should be thoroughly mixed before analysis.

The results of the analyses of these samples are shown in the following table:

Analyses of uniform samples of dynamite.

1	2	3	4	5	6	7	
Sample No.	Moisture.	Nitroglycerin.	Potassium nitrate.	Calcium carbonate.	Wood pulp.	Nitroglycerin.	
						By direct weighing.	By nitrometer.
A	1.21	43.90	39.14	1.02	14.73	....	....
B	.89	44.99	38.40	1.15	14.57	....	....
C	.99	44.77	38.75	1.06	14.59	....	....
D	.91	45.25	38.62	.98	14.24	....	....
E	1.05	44.52	38.05	1.28	15.10	....	....
F[a]	1.02	42.29	41.02	1.15	14.52	....	....
G	.41	44.91	39.04	1.12	14.52	....	....
H	1.35	44.86	38.09	1.28	14.42	....	....
J	1.22	44.98	38.48	.99	14.37	....	....
K[b]	....	....	....	....	....	....	....
L	1.60	44.50	37.40	1.00	15.50	....	....
M	1.00	45.70	37.57	1.17	14.56	....	....
N	1.19	45.50	37.54	1.15	14.62	....	....
O	1.15	45.48	37.69	1.16	14.52	45.87	45.22
P1	1.04	45.35	37.66	1.10	14.85	45.31	45.17
P2	1.26	45.22	37.33	1.20	14.88	....	....
P3	.98	45.24	37.87	1.21	14.70	....	....
Q	1.18	45.42	37.60	1.19	14.61	45.41	45.14

[a] The remarkable difference noted in the analysis of this sample as compared with all other samples, is due to the fact that, through misunderstanding, this sample was not mixed on being received. After several analyses had been made with widely varying results, the remainder of the sample was mixed by rubbing through sieves. This treatment probably resulted in considerable loss of nitroglycerin. Sample F is therefore not considered in the discussion of results.

[b] No report received.

Samples A to L were analyzed in the laboratories of various powder companies and samples M to Q in the bureau's laboratory; P2 and P3 were analyzed by men under instruction, not members of the laboratory force of the bureau.

DISCUSSION OF ANALYSES.

MOISTURE.

The methods employed were as follows:

Samples E, J, and M to Q, inclusive—3 grams desiccated on watch glass over H_2SO_4 for 3 days (0.98–1.26 per cent).

Sample A—6 to 10 grams on watch glass, 3 days over H_2SO_4 (1.21 per cent).

Sample B—3 grams on watch glass, 2 days over $CaCl_2$ (0.89 per cent).

Sample D—6 grams on watch glass, 24 hours over H_2SO_4 in vacuum (0.91 per cent).

Sample C—2 grams on watch glass, 24 hours over H_2SO_4, 15 inches vacuum (0.99 per cent).

Sample H—5 grams in Gooch crucible, 48 hours over H_2SO_4 at 40° C. (1.35 per cent).

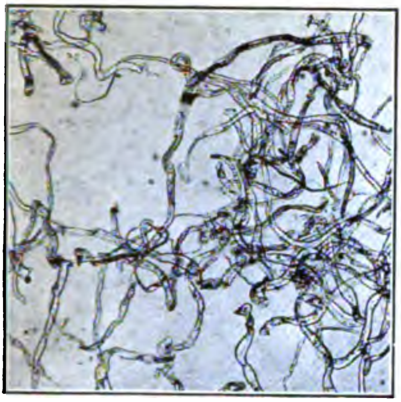
Sample G—10 grams in 4-ounce bottle, dry-air current passing *over surface* of sample for 24 hours (0.41 per cent).

Sample L—10 grams in drying tube, dry-air current passing *through* sample for 24 hours (1.60 per cent).

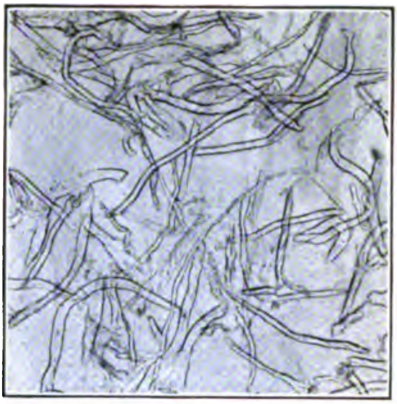
It is noted that desiccation on a watch glass over H_2SO_4 for three days gave only 0.3 per cent maximum variation, results obtained with the aid of vacuum for 24 hours being a little low. Two days over $CaCl_2$ gave low results. High results were obtained by desiccating at 40° C. and by passing dry air through the sample, from loss of nitroglycerin under these conditions. Passing dry air over the surface of the sample gave low results, as might be expected.

NITROGLYCERIN.

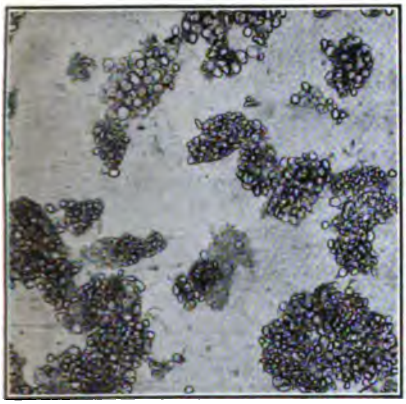
The results obtained in the bureau's laboratory with samples M to Q varied from 45.22 to 45.70 per cent. Samples of 5 to 10 grams in Gooch crucibles were extracted for one hour with U. S. P. ether (96 per cent) in the Wiley apparatus and the residues dried five hours at 100° C. The loss in weight minus the moisture previously determined was taken as the nitroglycerin content. Samples B, E, and J were analyzed in the same manner, giving results from 44.52 to 44.99 per cent. Samples A, C, D, G, and L were extracted with ether by means of suction, 7 to 10 grams of sample being treated with five or six successive portions of ether (amounts varying from 50 to 120 c. c.). Samples A, C, and D were dried to constant weight in steam ovens after extracting (the time of drying not noted); G was dried at 100° to 105°, and L for two hours at 95°. The results varied from 43.90 to 45.25 per cent. The results obtained in the bureau's laboratory (45.22 and 45.70 per cent) are uniformly higher than those obtained in other laboratories (43.90 to 45.25 per cent).



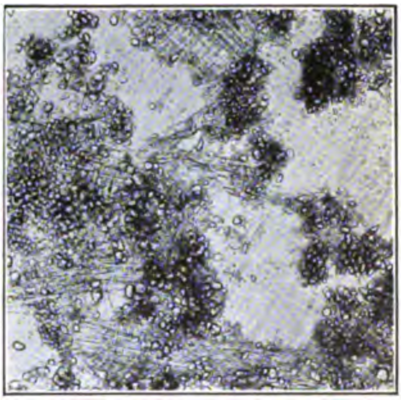
A. CELLULOSE (COTTON) (X 50).



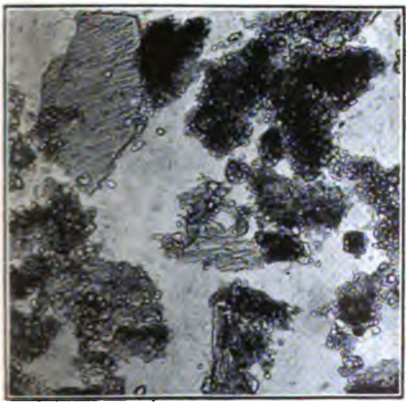
B. NITROCELLULOSE (X 50).



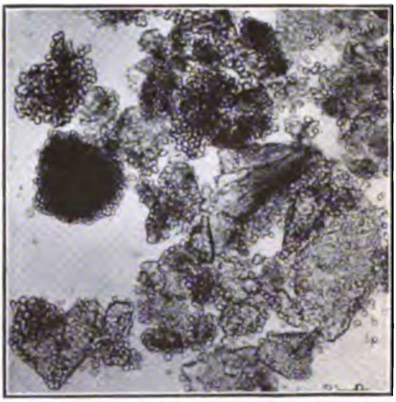
C. WHEAT FLOUR (FINE) (X 50)



D. WHEAT FLOUR (FINE) AND WOOD PULP (X 50).



E. WHEAT FLOUR (MIDDLINGS) (X 50).



F. CORN MEAL (X 50).

Nitrometer determinations on three samples (column 7) showed the true nitroglycerin content of the evaporated ether extracts to be approximately 45.2 per cent.

No explanation can be given for the large number of results in which the amounts of nitroglycerin found are uniformly low, except failure to observe one or more of the following precautions: (1) The extraction must be complete; (2) the residue must be dried to constant weight at a temperature of about 100° C.; (3) the dried residue must be cooled in an efficient desiccator and weighed as soon as cooled.

POTASSIUM NITRATE.

The results obtained in the bureau's laboratory varied from 37.33 to 37.87 per cent. The determination was made by extracting the residue insoluble in ether with about 200 c. c. of water, and determining the nitrate in an aliquot part of the water solution by evaporation, as described on page 44. No correction was made for traces of chlorides, etc., in the solution. The determination on sample H was made in the same manner, giving 38.09 per cent, while on sample L an aliquot portion of the water extract was analyzed in the nitrometer with a result of 37.40 per cent. All the remaining samples were extracted with water, the insoluble residues dried at about 100C°. and weighed, the loss of weight being regarded as potassium nitrate. This method gave high results (38.05 to 39.14 per cent) owing to the water-soluble organic matter extracted from the wood pulp.

CALCIUM CARBONATE.

In samples L to Q the calcium carbonate was determined gravimetrically in the dilute-acid extract; in samples C and D by direct titration of the residue insoluble in water, or of the ash left after burning off the pulp; in A, B, E, and J the loss of weight on extraction with dilute acid was considered as calcium carbonate, while in G and H the ash was assumed to be entirely calcium carbonate. The variations are of minor importance and no conclusions can be drawn from the results.

WOOD PULP.

Variations in the method of determining the potassium nitrate influence the proportion of wood pulp reported. When the loss of weight on extracting with water is assumed to be entirely potassium nitrate, in spite of the fact that it contains considerable organic matter extracted with the wood pulp, the proportion of wood pulp found will be lower than if the nitrate is determined by a direct method and the wood pulp by difference. The percentage of wood pulp being found by subtracting the sum of all other constituents from 100 per cent, no comparison of results is possible.

GELATIN DYNAMITE.

Unlike ordinary dynamite, which contains nitroglycerin absorbed in a porous material, gelatin dynamite contains nitroglycerin combined with nitrocellulose to form a plastic solid. When nitroglycerin is warmed with nitrocellulose containing about 12 per cent of nitrogen, the nitroglycerin dissolves the nitrocellulose, and a thick, viscous mass is produced which resumes a jelly-like consistency as soon as it has cooled. When as little as 3½ per cent of nitrocotton is dissolved in nitroglycerin at 60°, the material should form a jelly-like nonflowing mass when cooled to ordinary temperatures, but when smaller amounts of nitrocellulose are used the viscosity of the solution becomes less. The explosive known as "blasting gelatin" consists of about 93 to 90 per cent of nitroglycerin and 7 to 10 per cent of nitrocellulose, and is a translucent, jelly-like mass, containing the highest percentage of nitroglycerin used in any solid explosive.

Any explosive containing nitroglycerin combined with nitrocellulose in connection with an active base consisting of a nitrate and combustible material is termed a "gelatin dynamite." The gelatin dynamites have many properties that make them desirable for mining work, their greatest advantage being that they are almost unaffected by water.

SAMPLING.

The coherent, pasty, doughlike consistency of gelatin dynamite renders the preparation of a uniform sample much more difficult than is the case with ordinary dynamite.

A sample is prepared from one or more cartridges by cutting off portions from different parts of each stick; these portions are then cut into thin pieces and broken up as finely as possible by means of an aluminum or platinum spatula. The use of a steel spatula or knife is not to be recommended. The sample so prepared is well mixed and bottled, and because of its tendency to form a solid mass again on standing, it should be analyzed as soon as possible after being prepared.

The ingredients that may be found in the various types of gelatin dynamite are nitroglycerin; nitrocellulose; sulphur; rosin; sodium, potassium, or ammonium nitrate; calcium or magnesium carbonate; wood pulp; and cereal products.

Moisture is determined in the manner previously described.

The extraction with ether is made as for dynamite except that ether distilled over sodium (that is, ether free from alcohol) is used in order to avoid the partial solution of the nitrocellulose. Nitrocellulose is insoluble in pure ether, but a small percentage of alcohol present as an impurity may cause the solution of a considerable proportion of this constituent, and as the amount of nitrocellulose is usually only 0.5 to 2 per cent its determination should be accurate.

The ether solution containing the nitroglycerin, sulphur, and rosin is treated in the manner already described, and the water extraction of the dried and weighed insoluble residue is made in the usual way.

SULPHUR.

If the percentage of sulphur is unusually high, or if the extraction with ether has not been continued long enough, some sulphur may remain in the dried residue left after water extraction, in which case an additional extraction is made with carbon disulphide in the Wiley apparatus, the same method as described for the ether extraction being used. After the extraction with carbon disulphide has been made, the crucibles should be sucked dry and the carbon disulphide allowed to evaporate in a warm place before the crucibles are placed in the oven, as the vapors of carbon disulphide are very inflammable and may ignite in the oven. The crucibles with their dried residue are weighed and the loss of weight considered as sulphur.

The extraction with water is next made as before described.

NITROCELLULOSE.

Nitrocellulose is now removed by means of a suitable solvent. The pyroxylin cotton usually employed as a gelatinizing agent is soluble in a mixture of two parts ether and one part alcohol, but as all grades of nitrocellulose are more readily soluble in acetone than in ether alcohol it is customary to use acetone as the solvent.

The extraction with acetone is made by separating the dry residue from the crucible, leaving the mat intact if possible, placing the residue in a small beaker and covering it with acetone. The mixture is allowed to stand for three to four hours, with frequent stirring to dissolve completely the nitrocellulose, and is then filtered through the original crucible, washed with acetone, dried in the usual manner, and weighed. The loss of weight represents nitrocellulose plus a small amount of extract from the wood pulp. The wood pulp extract is usually so small that it may be disregarded, but a check on the nitrocellulose determination may be made by evaporating the acetone solution to a small volume (about 20 c. c.), and diluting gradually with a large volume of hot water (about 100 c. c.), which drives off the volatile solvent, precipitating the nitrocellulose as a white flocculent mass. The precipitate is then filtered off, dried, and weighed as nitrocellulose.

The remainder of the analysis is conducted as is that described for straight dynamite.

Some of the older types of gelatin dynamites contained small amounts (1 to 2 per cent) of paraffin, but this is an unusual ingredient and is more frequently found in ammonia dynamite. (See p. 57.)

Ammonia gelatin dynamite is a type that has of recent years assumed commercial importance. It differs from ordinary gelatin dynamite in the fact that it contains ammonium nitrate in addition to the usual constituents of the former. As in the ammonia dynamites, discussed later, so here the ammonium nitrate is usually previously coated with vaseline, paraffin, or other waterproofing material, and is neutralized with zinc oxide.

In the analysis of gelatin dynamite it should be remembered that trade custom has led to an erroneous system of designating the strength of explosives of this class. Thus a gelatin dynamite containing about 30 to 33 per cent of nitroglycerin and about 1 per cent of nitrocotton is called a "40 per cent" strength gelatin dynamite. This unfortunate practice undoubtedly had its origin in the fact that, as gelatin dynamite is much denser than ordinary dynamite, and a greater quantity can therefore be placed in a hole, it was assumed to be stronger. Comparative tests indicate that, weight for weight, a so-called "40 per cent" strength gelatin dynamite containing 33 per cent nitroglycerin is much weaker than is an ordinary "straight" dynamite containing 40 per cent nitroglycerin.

AMMONIA DYNAMITE.

The usual type of ammonia dynamite is practically a "straight" dynamite in which a large part of the nitroglycerin is replaced by ammonium nitrate. Sulphur is sometimes a constituent of this type of explosive, and frequently the wood pulp is wholly or largely replaced by coarse flour or middlings. The ammonium nitrate is generally protected from hygroscopic influence by a coating of vaseline or paraffin and is neutralized with zinc oxide. These ingredients are added to the ammonium nitrate in the course of its manufacture while the crystals of the ammonium nitrate are still hot.

In the analysis of such explosives the determination of moisture and extractions with ether, water, and acid are carried out as previously described. An additional extraction with carbon disulphide is usually necessary in order to remove all of the sulphur; this is done after the water-soluble salts have been extracted.

One portion of the ether extract is used for the determination of nitroglycerin in the nitrometer and the other for the determination of the sulphur and vaseline or paraffin.

The method for the analysis of the ether extract as described on pages 41 and 42 is the scheme of separation followed when both sulphur and vaseline, or paraffin, are present with the nitroglycerin, although several other methods are applicable and give reliable results.

The nitroglycerin may be destroyed by means of caustic alkali, which also dissolves any resin present; the solution is decanted from the residue of paraffin, or vaseline, and sulphur; the resin is precipitated with hydrochloric acid, filtered, dried, and weighed. The residue of sulphur and paraffin or vaseline is treated with hot ammonium sulphide which dissolves the sulphur; this solution is cooled, decanted, and the vaseline or paraffin adhering to the beaker is washed, dried, and weighed. The weight of sulphur is found by difference.[a]

The water extract contains both ammonium and sodium nitrates, together with water-soluble organic material from the flour or other absorbent. If zinc oxide has been used as the antacid, all of this component will generally be found in the water extract, since the small amounts used are readily soluble in ammonium nitrate solutions.

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, pp. 388–389.

An aliquot part of the water extract is evaporated in a platinum dish on a steam bath, the ammonium nitrate volatilized, and the organic matter burned off by careful heating over a burner. A little nitric acid is added to oxidize to nitrate any nitrite resulting from reduction, as described on page 44. In heating this residue care must be taken to avoid decomposition of the zinc nitrate, or else the heating should be strong enough to convert it entirely to zinc oxide. Either of the following methods may be used:

(1) The residue, after evaporation of the nitric acid on the steam bath, is dried at about 110° to 120°, and weighed as $NaNO_3$ and $Zn(NO_3)_2$. This residue is then dissolved in water and the zinc precipitated with sodium carbonate, filtered, ignited, and weighed as ZnO. The weight of $NaNO_3$ and $Zn(NO_3)_2$ minus (2.33 times the weight of ZnO) equals $NaNO_3$.

(2) The residue obtained as above is heated gently over a burner until the evolution of oxides of nitrogen from the decomposition of the zinc nitrate has ceased, care being taken that the temperature is not high enough to cause a loss of sodium nitrate. The residue is now weighed as $NaNO_3$ plus ZnO, then treated with water to dissolve the $NaNO_3$; the ZnO is filtered on a Gooch crucible, ignited, and weighed as ZnO, the $NaNO_3$ being found by difference from the combined weight. The filtrate containing the sodium nitrate should be tested with ammonium sulphide to assure that the zinc has been entirely converted to insoluble zinc oxide.

Zinc may be determined in a separate portion of the water extract by adding ammonia, precipitating with hydrogen sulphide, and filtering off the precipitated zinc sulphide. The precipitate is washed and, without drying, dissolved in a small amount of nitric acid, and evaporated to dryness. Any free sulphur is thus oxidized. The residue is treated with a little sulphuric acid and again evaporated to dryness over a burner at a dull-red heat until the free acid has been volatilized. Little, if any, decomposition of the zinc sulphate results from this heating. The treatment with sulphuric acid and heating should be repeated until a constant weight of $ZnSO_4$ is obtained. This method is convenient and has been found to check well with the methods described above.

Ammonium nitrate is determined directly with a separate portion of the water extract by the usual method of distilling from a solution made strongly alkaline with KOH, collecting the distillate in a known volume of standard H_2SO_4, and titrating the excess of acid with standard alkali, cochineal being used as an indicator.

In regard to the determination of ammonium nitrate, the possible effects of several influencing factors have been investigated. Stillman and Austin state that ammonium nitrate is slightly soluble in ether,[a] and several other authors have noted that correction should be made for this solubility.

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[a] Kast, H.. Anleitung zur chemischen und physikalischen Untersuchungen der Spreng- und Zündstoffe, 1909, p. 980.

Ten-gram samples of pure ammonium nitrate were desiccated to constant weight over sulphuric acid and were extracted with U. S. P. (96 per cent) ether for one hour in the Wiley apparatus. On drying to constant weight in vacuum desiccators a maximum loss of only 0.10 per cent was noted. Additional drying of the same samples at 70° for 18 hours caused a further loss of 0.07 to 0.15 per cent. On continuing the drying at 90° to 100° further losses calculated as percentages of the original sample were as follows:

Loss in weight of ammonium nitrate dried at 90° to 100°.

Time of drying.	Total loss, per cent.	
	Sample 1.	Sample 2.
Hours.		
2	0.03	0.04
5	.03	.05
24	.07	.11
120	.33	.39
240	.62	.67

The above-mentioned experiments show that the loss of pure ammonium nitrate by the ether extraction and by subsequent drying for several hours at 70° or 100° is very slight—not over 0.25 per cent.

That the loss on drying depends on the surface exposed was shown by drying, at 90° to 100°, 5-gram samples spread on 3-inch watch glasses. The losses were as follows:

Loss in weight of ammonium nitrate dried on 3-inch watch glasses at 90° to 100° C.

Time of drying.	Loss of weight, per cent.	
	Sample 1.	Sample 2.
Hours.		
5	0.34	0.33
24	.88	.98
48	2.03	1.57
120	6.11	4.64
168	7.09	5.84

In this case the much greater surface of samples exposed caused a much more rapid volatilization.

In the analysis of an explosive containing zinc oxide, it must be remembered that in addition to mere volatilization there is possible still further loss from the decomposing action of the ZnO on the ammonium nitrate. This is shown by the following experiment: Two 10-gram samples of ammonium nitrate were ground in a mortar, 0.5 gram zinc oxide being well mixed with one sample. The two samples were then placed in crucibles and heated at 100°. The losses in weight are given in the table following:

Loss in weight of ammonium nitrate with and without zinc oxide on heating at 100°.

Time.	Loss in weight, per cent.	
	Ammonium nitrate.	Ammonium nitrate plus 5 per cent of zinc oxide.
Hours.		
2	0.02	0.61
18	.11	1.07
48	.16	1.13

The effect of too high temperature of drying is shown more clearly in the following experiments with an ammonium nitrate explosive of the "permissible" class, containing nitroglycerin. The explosive contained about 75 per cent of NH_4NO_3 and 1.4 per cent of ZnO. Six 10-gram samples were extracted with ether in the usual manner to remove the nitroglycerin. Two of the extracted samples were dried over night at 100° C., two over night at 70° C., and two for 24 hours in vacuum desiccators to constant weight. The samples were then extracted with water, dried five hours at 100° C., and the loss in weight noted. Ammonium nitrate was determined in the water solutions by the distillation method previously described. The results are tabulated below:

Effect of different methods of drying ammonium nitrate explosives after ether extraction.

[Determinations by J. H. Hunter.]

Method of drying.	Loss of weight, per cent.						NH_4NO_3 in water solution, per cent.		
	Ether extraction.			Water extraction.					
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
In a 100° oven	13.48	13.10	13.29	77.58	77.23	77.40	....	71.76	71.76
In a 70° oven	11.72	11.64	11.68	79.29	79.09	79.19	75.01	74.78	74.90
In a vacuum desiccator	11.68	11.57	11.63	79.22	79.11	79.17	75.31	75.20	75.25

These results show clearly that drying at 100° after extraction with ether causes a considerable loss of ammonium nitrate, most of the loss being due to decomposition of the nitrate by the zinc oxide.

The sum of the amounts of sodium nitrate, ammonium nitrate, and zinc oxide found in the water solution will be less than the total water extract, since the latter, as before noted, includes water-soluble organic material from the wood pulp, flour, or other carbonaceous absorbents. This organic material is added to the amount of starch, etc., removed by hydrolysis and reported as "starch," as has been noted on a previous page.

LOW-FREEZING DYNAMITE.

Nitroglycerin congeals or freezes at a temperature of about 8° C. (46° F.), and as nitroglycerin in the frozen condition is much less sensitive to the action of a detonator than when in the liquid condition, explosives containing frozen nitroglycerin usually fail to explode when attempts are made to use them.

As the outdoor temperature for several months in the year is on the average below the temperature at which nitroglycerin explosives freeze, many efforts have been made to prepare low-freezing explosives, which, without being thawed, may be used at temperatures lower than that at which ordinary nitroglycerin explosives are frozen. Some types of nonfreezing explosives contain ammonium nitrate mixed with nitrostarch, nitrotoluene, or similar material, but those explosives to which the term "low-freezing" is usually applied contain nitroglycerin mixed with the liquid nitrotoluenes, with crystalline dinitrotoluene or trinitrotoluene, with the nitrochlorhydrins or other materials, it having been shown, for example, that 20 per cent of dinitrochlorhydrin in nitroglycerin reduces the temperature at which the mixture will freeze to about —12° C.,[a] and by the use of mixtures of nitroglycerin and dinitrotoluene explosives are prepared which may be used at temperatures considerably below 0° C.

Many low-freezing explosives are marked with the designation "L. F." upon their wrappers; but even in the absence of this notice of the nature of the explosive a low-freezing dynamite may frequently be distinguished by the odor of nitrotoluene, or by the color test for nitrosubstitution compounds made on the ether extract as described under "Qualitative examination," on pages 17 and 18.

DETERMINATION OF NITROSUBSTITUTION COMPOUNDS.

With low-freezing dynamites the methods of sampling and of determination of moisture are carried out in the manner already outlined. The extraction with ether is also made in the usual manner, and one of the samples of ether extract is used, as outlined on a preceding page, for the determination of resins, sulphur, or other ingredients. The other sample of ether extract is used for the determination of the nitroglycerin and nitrosubstitution products.

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[a] Roewer, F. A., Proc. 6th Int. Cong. App. Chem., vol. 1, 1906, p. 541.

So far as is known by the writers, no satisfactory method has yet been found for the direct determination of nitrosubstitution compounds in the presence of nitroglycerin. The analysis of such mixtures is generally made by determining the nitroglycerin by means of the nitrometer (p. 35), and finding the amount of nitrosubstitution compound by difference. The nitrosubstitution compounds are not decomposed in the nitrometer as are the nitric esters.

It is interesting to note, however, that if mononitrotoluene is present the amount of nitroglycerin found by means of the nitrometer does not represent the true amount of this ingredient in the mixture. It has been found[a] that a portion of the nitric acid liberated from the nitroglycerin by the action of the sulphuric acid used in the determination is taken up by the mononitrotoluene present, the latter becoming quantitatively nitrated to dinitrotoluene. Thus, if the amount of nitroglycerin in the ether extract is not in excess of the theoretical amount required to yield sufficient nitrogen to convert all the mononitrotoluene to dinitrotoluene, no evolution of nitric oxide will result. In other words, the error in the determination of nitroglycerin is equal to about 0.5530 gram of nitroglycerin for each gram of mononitrotoluene present. Pure crystalline dinitrotoluene or trinitrotoluene was found to have no effect on the determination, and the same was found to be true of the so-called "liquid trinitrotoluene." "Liquid dinitrotoluene," however, causes an error amounting to 0.0628 gram of nitroglycerin for each gram of the nitrosubstitution product. This error was shown to be probably due to the presence of mononitrotoluene in the liquid dinitrotoluene.

These results show that the nitrometer method for determination of nitroglycerin is not reliable if mononitrotoluene is present. The latter is, however, seldom used in low-freezing dynamites, and in the case of the more commonly used liquid dinitrotoluene, the resulting error is not large. For example, in an explosive containing 25 per cent of nitroglycerin and 10 per cent of liquid dinitrotoluene, the error in the determination of nitroglycerin would amount to 0.628 per cent, or the amount of nitroglycerin found would be 24.37 per cent instead of 25 per cent.

Further information may be gained by determining the total nitrogen of both the nitroglycerin and the nitrosubstitution compound by a modification of the Kjeldahl method and deducting the nitrogen of the nitroglycerin, the difference being the nitrogen of the nitrosubstitution compound. From this nitrogen the amount of the latter can be calculated. This method is of value only if the nitrosubstitution compound has been identified by the preliminary examination.

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[a] Storm, C. G., The effect of nitrotoluenes on the determination of nitroglycerin by means of the nitrometer, Proc. 8th Int. Cong. App. Chem., vol. 4, 1912, p. 117.

Another method for the determination of the total nitrogen of such mixtures, as well as the ester nitrogen, is that of Berl and Jurrissen,[a] in which a so-called "decomposition flask" is used. By means of sulphuric acid and a small amount of mercury in a vacuum the decomposition of nitroglycerin or other nitric ester is effected and the resulting volume of nitrogen oxide (NO) measured. A second sample of the mixture is treated in the same manner after a preliminary oxidation with chromic acid and sulphuric acid, whereby the total nitrogen is converted to nitrogen oxide (NO). The difference between the two volumes of nitrogen oxide (NO) equals that resulting from the nitrosubstitution compound.

The remainder of the analysis—the extractions with water, acid, etc.—is conducted in the manner previously described and should present no further difficulties.

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[a] Berl, E., and Jurrissen, A. W., Über gasvolumetrische Analyse mit dem "Zersetzungskolben" und die Stickstoffbestimmung in rauchschwachen Pulvern. Zeitschr. angew. Chem., vol. 23, 1910, p. 241.

GRANULATED NITROGLYCERIN POWDER.

When ordinary dynamite is used in blasting any material of a consistency resembling that of earth or clay, little of the energy of the explosive does useful work, because the soft and compressible nature of the material blasted allows the greater part of the energy of the explosive to be used in compacting the material and in producing a cavity. Consequently, gunpowder has been largely used in all places where earth, clay, or other soft material was to be dislodged. In the blasting of the banks of railroad cuts there are often places where a soft, but somewhat consolidated material, intermediate between earth and hard rock, has to be blasted. Such a material might be a soft shale, for example, or a friable and easily crumbled sandstone, and for dislodging it neither ordinary blasting powder nor ordinary dynamite is particularly suitable. In the year 1876 E. Judson patented an explosive consisting of a low-grade gunpowder made by heating and mixing together coal, sulphur, sodium nitrate, etc., granulating the mixture, and then coating this non-absorbent granulated dope with a small amount of nitroglycerin. The proportion of nitroglycerin used—often as little as 5 per cent—was such that had it been absorbed by the grains of explosive it would not have been capable of detonation, but by remaining wholly or largely upon the surface of the grains the use of a detonator brought about its explosion and the simultaneous ignition of the gunpowder base which it covered. Such an explosive, as a result of the detonation of the nitroglycerin, produces an initial blow sufficient to crack and fissure the partly consolidated material in which it is placed. The action of the gunpowder mixture that forms the larger part of the explosive so heaves and moves the broken-up mass as to make easy its removal with steam shovels.

Granulated nitroglycerin powders, or "free-running" explosives, have been very much used in the excavation of earth and are commonly known as Judson powder (after the inventor), bank powder, or railroad powder. In the analysis of low-grade granular powder, moisture is determined by the standard method, and the usual method of extracting with ether is followed. In the ether extract are usually found large proportions of sulphur, rosin, etc., besides the nitroglycerin. The proportion of sulphur commonly used in low-grade granular powder is so considerable that usually it is not all removed by extraction with ether.

The determination of nitrates in the residue after ether extraction is made in the manner already outlined for ordinary dynamite; an additional extraction with carbon disulphide is necessary to remove the sulphur not extracted by means of ether.

As antacids are seldom added to low-grade granular explosives, the extraction with dilute acid may generally be omitted; but if the qualitative examination has indicated the presence of an antacid, its determination is made as already described.

The residue remaining after the extractions with ether, water, and carbon disulphide is usually bituminous coal, although charcoal or other carbonaceous material may be found. An examination under the microscope or with a hand magnifier will usually show with sufficient certainty the nature of the insoluble residue, and the presence of bituminous coal may generally be confirmed by a volatile-matter determination made by heating the solid residue in a small crucible over a Bunsen flame.

The separation and determination of the ingredients of the ether and water extracts is carried out by the methods previously described.

BLACK POWDER.

The general term "black powder" is applied to several explosives of nearly similar composition, including chiefly black blasting powder, black gunpowder, and black fuse powder. As their chemical examination involves identical problems, they are here treated as one general class.

Black blasting powder usually consists of a mixture of sodium nitrate, sulphur, and charcoal, whereas black gunpowder is generally a mixture of potassium nitrate, sulphur, and charcoal. The real difference between "gunpowder" and black blasting powder is one of use, since some blasting powder containing potassium nitrate as the oxidizing material has been made, and, similarly, there is record of gunpowder having been made from sodium nitrate. Although black blasting powder is usually made in larger grains than gunpowder, yet for certain purposes, particularly for large cannon, grains of gunpowder have been made even larger in size than the customary kinds of blasting powder, and again finely granulated blasting powder has been made for use where a quick-acting explosive, yet one not so rapid as dynamite, was desired.

The black-powder composition used in the ordinary miner's safety fuse and known as "fuse powder" is much similar to the ordinary grade of gunpowder, but is of very fine granulation (usually 40 to 100 mesh), and contains potassium nitrate as its oxidizing agent.

PHYSICAL EXAMINATION.

GRANULATION OR AVERAGE SIZE OF GRAINS.

The determination of the granulation of black powder is made by a series of standard sieves, but this examination is not usually required in connection with chemical analysis, and can be made only where a large sample of the powder is available. The standard sizes of grains of black blasting powder, together with a statement of the size of screen through which the material will pass, is given in the following tabulation:[a]

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[a] Munroe, C. E., and Hall, Clarence, A primer on explosives for coal miners. Bureau of Mines, Bull. 17, 1911, p. 17.

Relation between sizes of black blasting powder and separating sieve.

Size of grains.	Diameter of round holes in screens through which grains pass.	Diameter of round holes in screens on which grains collect.
CCC	[illegible] inch	[illegible] inch
CC	[illegible] inch	[illegible] inch
C	[illegible] inch	[illegible] inch
F	[illegible] inch	[illegible] inch
FF	[illegible] inch	[illegible] inch
FFF	[illegible] inch	[illegible] inch
FFFF	[illegible] inch	(a) [illegible] inch

[a] Or 28-mesh bolting cloth.

GRAVIMETRIC DENSITY.

By "gravimetric density" is meant the "apparent specific gravity" of the explosive, or the ratio that the weight of the powder contained in a given volume bears to the weight of water that would exactly fill the same volume. Gravimetric density or apparent specific gravity is therefore not only a factor of the true density of the powder, but is also influenced by the size and the shape of the grains, since obviously the space occupied by voids, or the space between grains, must vary with the shape and size of the grains.

The standard determination of gravimetric density is made by pouring the powder into a vessel, usually in the shape of the frustrum of a cone, striking off with a straightedge all over that required to fill the measure, and then weighing the powder held by the receiver. Plate II, *B*, shows a commercial type of gravimetric balance for this purpose. With this balance direct readings of the gravimetric density of a powder are possible without calculation. When so few determinations must be made as to make the use of a separate instrument seem unnecessary, the determination of the weight of powder contained in a cylindrical graduate of known volume, or a standard pint or quart measure, may be made. In all cases the gravimetric density is the ratio expressed by dividing the weight of powder required to fill the measure even full by the weight of water from the same measure even full.

The gravimetric density of black powders varies over a considerable range, from about 1 to 1.3.

ABSOLUTE DENSITY.

By "absolute density" is meant the true specific gravity of the powder, the air space between grains being disregarded and only the density of the grains being considered. Owing to the fact that both sodium and potassium nitrates are readily soluble in water, it is not possible to make this determination with black powder by the picnometer method with water, so that a number of instruments involving the use of mercury have been designed by different investigators.

The form of instrument used by the Bureau of Mines is illustrated in figure 5, and was devised by one of the authors.[a] The apparatus consists of a reservoir and means for introducing within this reservoir a picnometer bottle containing the powder whose density is to be determined. By opening the water-supply valve the mercury is raised within the reservoir, and on closing it and opening the waste-pipe valve the water pressure is removed from the mercury in the lower reservoir. A Torricellian vacuum is thus created in the dome above the bottle; most of the air in the bottle escapes and is replaced with mercury. The operation is repeated until the air in the bottle is completely replaced. With this instrument the determination of the absolute density of black powder may be quickly and accurately made.

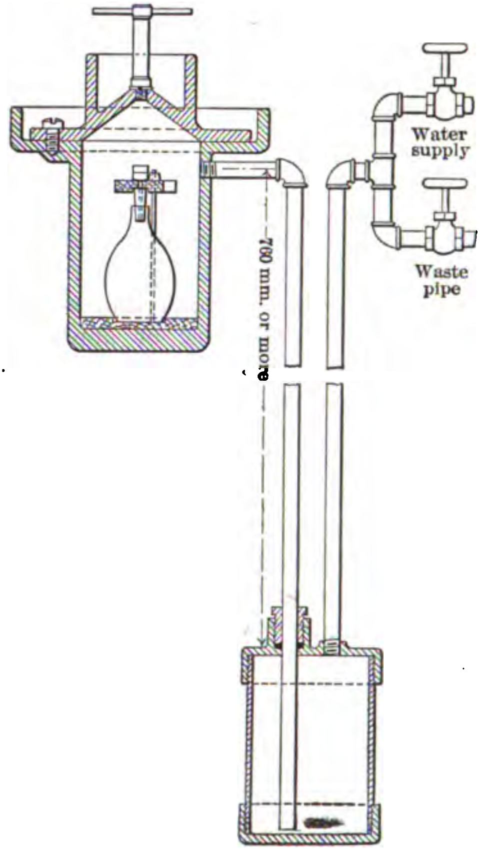

FIGURE 5.—Densimeter.

SAMPLING.

About 50 to 100 grams of the original sample is crushed in small portions in a porcelain mortar and passed through an 80-mesh sieve. All precautions are taken to avoid unnecessary exposure of the sample to the air during this treatment. If each portion is placed in a stoppered bottle as soon as sifted, there is no appreciable change in hygroscopic moisture content. The powdered sample is well mixed before its analysis is begun.

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[a] Snelling, W. O., Improved densimeter. Proc. 8th Int. Cong. App. Chem., vol. 4, 1912, p. 105. (Chem. Abs., vol. 6, 1912, p. 3524.)

CHEMICAL EXAMINATION.

The chemical examination of black powder consists essentially of the determination of the amounts of moisture, nitrate, sulphur, and charcoal present. The nitrate is readily separated from the sulphur and charcoal by the solvent action of water, and after the residue from water extraction has been carefully dried the sulphur may be readily separated from the charcoal by the action of carbon bisulphide, or other solvent.

The charcoal is always determined by difference. After being dried the charcoal is usually ignited and its content of ash determined.

DETERMINATION OF MOISTURE.

The determination of moisture is carried out exactly as has been described in the analysis of dynamite (p. 20), a 2-gram sample being spread on a 3-inch watch glass and desiccated for three days over sulphuric acid. It is customary in some explosives laboratories to determine moisture on a sample that is crushed only sufficiently to pass through a 10 to 12 mesh sieve, because in further pulverization the moisture content of the powder may be influenced by atmospheric conditions. Comparative determinations have indicated, however, that unless there is undue exposure in preparing the sample the difference in moisture content between the coarse and the finely powdered sample is slight, and since the nature of black powder is such that a finely powdered sample must be used for chemical analysis it is considered much more convenient to use the same for the moisture determination.

Many authorities recommend that moisture in black powder be determined by drying in an oven at temperatures of 60° to 100° C.[a] As sulphur is more or less volatile at temperatures even slightly above ordinary, the authors thought it advisable to compare the relative merits of oven drying with the desiccation method. A series of determinations was therefore made on large, well-mixed samples of finely ground powder (80-mesh), 2 grams spread uniformly in a thin layer on a 3-inch watch glass being used for each determination. The samples heated in ovens were allowed to cool for 15 minutes in desiccators before weighing. It was found necessary to make the weighings as rapidly as possible in order to prevent increase of weight. The following results were obtained.

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[a] Lunge, G., and Berl, E., Chemisch-technische Untersuchungsmethoden, vol. 3, 1910, p. 116; Guttmann, O., Schiess- und Sprengmittel, 1900, p. 48.

Results of determinations of moisture in black powder.

SAMPLE A.

[Determinations by W. C. Cope.]

Time.	Loss on desiccation over sulphuric acid.	Loss on drying at 70°.	Loss on drying at 100°.
Hours.	*Per cent.*	*Per cent.*	*Per cent.*
1	....	1.00	1.05
2	....	1.00	1.10
3	....	1.00	1.15
5	....	1.00	1.30
72	1.00	....	....

SAMPLE B.

[Determinations by C. A. Taylor.]

1	....	0.44	0.57
2	....	.46	.78
3	....	.50	.94
5	....	.54	1.07
7	....	.59	1.19
24	0.42—0.47	.74	3.70
72	0.46—0.49	....	....

The analysis (calculated moisture free) of sample B was originally as follows: Sodium nitrate, 74.07; sulphur, 10.09; charcoal 15.84. The sample dried 24 hours at 100°, with a loss of 3.70 per cent, was analyzed with the following result: Sodium nitrate, 77.0; sulphur, 6.53, charcoal 16.47. It is therefore evident that there is a loss of sulphur from black powder at 100°, and that this loss is appreciable in even a few hours' heating, whereas at 70° the loss for periods of heating up to five hours is approximately the same as the moisture determined by desiccation.

Desiccation gives practically constant weight in 24 hours, but as the loss of moisture takes place more slowly in coarser samples, a uniform period of three days has been adopted.

Sulphur alone is slightly affected by temperatures up to 100° C. A sample of approximately 5 grams of powdered brimstone (80-mesh) was desiccated for two days over sulphuric acid without loss of weight. It was then dried five hours at 70° C., losing only 0.003 per cent; further drying for five hours at 97° caused a loss of only 0.01 per cent.

EXTRACTION WITH WATER; DETERMINATION OF NITRATES.

In the determination of nitrates by extraction with water, about 10 grams of the finely ground sample is weighed in a Gooch crucible with asbestos mat and about 200 c. c. of water, in successive portions of 15 to 20 c. c. each, is drawn through the sample by means of suction. The complete solution of the nitrate is hastened by the use of warm or hot water, although 200 c. c. of cold water is usually sufficient. The final portions of water passing through the crucible should be tested for soluble nitrate by evaporation on a glass plate, or an excess of trong sulphuric acid containing a few crystals of diphenylamine may be added to a few drops of the water, and an intense blue coloration will indicate the presence of nitrate.

The extraction is made on duplicate samples as with dynamite. After the complete removal of the nitrate the crucibles containing the portion insoluble in water are placed in a drying oven at a temperature of about 70° and dried to constant weight, usually overnight, although five hours is generally sufficient. The percentage of loss of weight, minus the moisture content found as described above, represents the total water-soluble material, and includes, in addition to sodium or potassium nitrate, a small amount of water-soluble organic material from the charcoal and the impurities in the original nitrate, such as chlorides and sulphate. An aliquot portion of the water extract is evaporated to dryness on a steam bath, treated with a little nitric acid, again evaporated, heated to slight fusion, and weighed. (See p. 44.) For accurate analysis the amounts of chlorides and sulphates may be determined in separate portions of the water extract and the true nitrate content determined by difference, or a direct determination of nitrate may be made with the nitrometer on a portion of the extract, as previously described.

The water solution should, of course be tested to determine whether sodium or potassium nitrate is present. This determination is conveniently made by heating to redness a clean platinum wire dipped in the solution, and observing the color of the flame through several thicknesses of cobalt glass. Potassium is indicated by its characteristic red color, and the yellow of the sodium flame is entirely cut off by the blue glass. Without the cobalt glass a sodium nitrate powder should give an intense yellow flame and a potassium nitrate powder a pale pink or lavender flame. If both sodium and potassium nitrates are indicated, a determination of potassium is best made by the sodium-cobalti-nitrate method of Drushel,[a] or the proportions of sodium and potassium nitrates may be calculated with an approximate degree of accuracy from the total weight of nitrates found by evaporation and the percentage of nitrogen in the combined weight of these nitrates as determined by the nitrometer.

The following illustrates the method of calculation employed:

Let a = weight of both nitrates.
x = weight of sodium nitrate.
Then $a-x$ = weight of potassium nitrate.
Let b = percentage of nitrogen found in combined nitrates.
16.47 = percentage of nitrogen in sodium nitrate.
13.87 = percentage of nitrogen in potassium nitrate.

$$\text{Then } 0.1647x + 0.1387\ (a-x) = \frac{ba}{100}.$$

---

[a] Bowser, L. T., The determination of potassium by the cobalti-nitrate method. Jour. Ind. and Eng. Chem., vol. 1, 1909, p 791.

Solving for x gives the weight of sodium nitrate present in the mixture, and subtracting this from the total weight of the mixture gives the potassium nitrate.

EXTRACTION WITH CARBON DISULPHIDE; DETERMINATION OF SULPHUR.

The dried and weighed material left from the extraction with water consists of the sulphur and charcoal. The sulphur is determined by loss of weight on extraction with carbon disulphide in the Wiley extraction apparatus, the method being exactly the same as that used in the extraction with ether.

Because of the fact that it is difficult to obtain carbon disulphide that does not leave a residue of sulphur on evaporation, it is not customary to evaporate the carbon-disulphide extract to dryness and weigh the sulphur dissolved from the powder. This may be done, however, if freshly distilled pure carbon disulphide is used.

INSOLUBLE RESIDUE, CHARCOAL.

The residue remaining in the crucibles is weighed directly as charcoal after drying to constant weight at about 100°.

In drying the crucibles after the carbon disulphide extraction extreme care should be used to avoid setting fire to the inflammable vapor of the carbon disulphide, as it sometimes happens that the heavy vapor from the crucibles passes down to the flame by which the water oven is heated. Carbon disulphide has the lowest ignition temperature of any material not containing phosphorus, therefore in extracting with carbon disulphide, or in handling the crucibles after extraction, considerable care should be taken to avoid proximity to lights or fire.

DETERMINATION OF ASH.

The ash in the charcoal is determined by ignition over a Bunsen burner until all of the carbon has been burned off, and weighing. The ash is usually found to be about 0.5 to 1 per cent of the total powder. In case of an abnormally high ash value it is possible that the extraction with water was incomplete, leaving some nitrate undissolved.

The sulphur used in black powder is almost invariably brimstone, flowers of sulphur not being suitable for this purpose because of the invariable presence of acidity.

In those cases where flowers of sulphur are used, however, it should be noted that the extraction of the sulphur with carbon disulphide will be incomplete. Watts,[a] Gody,[b] and other authorities have called attention to the fact that flowers of sulphur always contain a considerable amount of insoluble amorphous sulphur, often amounting to as much as 35 per cent.

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[a] Watts's Dictionary of Chemistry, 1905, vol. 4, pp. 606–610.

[b] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 99.

Experiments made in the bureau's explosives laboratory with samples of brimstone and flowers of sulphur gave results as follows:

Relative solubility of flowers of sulphur and brimstone in carbon disulphide.

	Weight of sample.	Loss of weight on extraction.[a]	Insoluble substances.
	Grams.	*Grams.*	*Per cent.*
Flowers of sulphur	1.0907	0.7817	23.21
	1.0450	.7472	28.50
Brimstone	1.1238	1.1230	.07
	1.1004	1.0996	.07

[a] Extracted two hours in Wiley extraction apparatus with carbon disulphide.

In view of the fact that when flowers of sulphur are present the extraction with carbon disulphide is incomplete, some authors have recommended the use of hot aniline as a solvent for the sulphur.

The solubility of sulphur in various solvents is shown in the following table:[a]

Solubility of sulphur in 100 parts (by weight) of various solvents.

Solvent.	Temperature.	Parts (by weight) of sulphur dissolved.
	°*C.*	
Carbon disulphide	0	23.99
Do	15	41.65
Do	22	46.05
Do	38	94.57
Do	[a] 55	181.34
Benzene	26	.965
Do	71	4.377
Toluene	23	1.479
Ether	23.5	.972
Chloroform	22	1.205
Phenol	174	16.35
Aniline	130	85.96

[a] Boiling.

Of these solvents carbon disulphide and aniline are the ones that would appear to be of greatest practical value in analysis. Carbon tetrachloride, chloroform, and benzene have also been used with success as solvents for sulphur, but their use requires long-continued extraction.

Experiments have been made in the explosives laboratory of the bureau to determine the suitability of aniline as a solvent for sulphur in the analysis of black powder.

Extractions of both flowers of sulphur and brimstone with aniline heated to 130° to 140° showed only about 0.05 of 1 per cent insoluble material in each.

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 85. Biedermann, R., Chemiker Kalender, pt. 1, 1910, p. 291.

Several samples of black powder were analyzed, the sulphur being determined by means of extraction with hot aniline, and the results were compared with those obtained by the usual method of extraction with carbon disulphide. The extraction with the aniline was made by adding 10-c. c. portions of aniline, previously heated to 130° to 135° C. to the crucibles containing samples that had been extracted with water and dried in the usual manner, the hot aniline being drawn through by suction; this treatment was repeated from 5 to 12 times, using a total of 50 to 125 c. c. of aniline in different determinations. The last portions of aniline were removed by washing with a small amount of alcohol, and the residue dried at 100° C. The loss of weight was considered as the amount of sulphur present.

Comparative determinations of sulphur in black powder by extraction with carbon disulphide and aniline.

Sample No.	Sulphur extracted.	
	With carbon disulphide.	With aniline (130°).
1	13.64	13.79
2	9.99	9.72
3	7.81	7.74

Each of the above figures is the average of four to six closely agreeing results. This comparison shows that the aniline method gives very satisfactory results. Even as small an amount as 50 c. c. of aniline was found to be sufficient for complete extraction if each portion was allowed to stand a short time before sucking dry. The aniline may be readily recovered by distillation and used repeatedly.

A series of experiments were made to determine whether any difference in results would be effected by extracting the sulphur with carbon disulphide before the nitrate was extracted with water—that is, an inversion of the order of the extractions. A number of samples of black powder were analyzed by both methods with the results noted in the following tables. For comparison, determinations were made of the sulphur by precipitation as barium sulphate after oxidation with nitric acid and potassium chlorate.

Results of analyses of black powder.

[Samples A, B, and C analyzed by C. A. Lambert; sample D analyzed by C. A. Taylor.]

METHOD 1 (WATER EXTRACTION FIRST).

Sample.	Moisture.	Water extract.	Carbon disulphide extract.	Insoluble residue.	Sulphur determined as $BaSO_4$.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
A	0.16	69.76	13.64	16.44	13.55
	.16	69.73	13.55	16.56	
B	.21	74.07	10.09	15.63	10.06
	.21	74.27	9.89	15.63	
C	.36	78.88	7.87	12.89	7.89
	.36	78.98	7.68	12.98	
	.36	78.91	7.89	12.84	
D	.47	73.84	10.02	15.67	....
	.47	73.74	10.06	15.73	
	.47	73.79	10.04	15.70	

METHOD 2 (CARBON DISULPHIDE EXTRACTION FIRST).

A	0.16	69.58	13.74	16.52	13.55
	.16	69.57	13.80	16.47	
B	.21	73.97	10.39	15.43	10.05
	.21	73.92	10.44	15.43	
C	.36	78.45	8.47	12.72	7.89
	.36	78.54	8.49	12.61	
D	.47	73.91	10.15	15.47	....
	.47	73.74	10.25	15.54	
	.47	73.82	10.20	15.51	

It will be noted that in every case a greater loss was obtained on extracting with carbon disulphide when such extraction preceded the extraction with water than when it followed the extraction with water. That a more correct value for the amount of sulphur present is obtained by first removing the water-soluble portion of the powder, is shown by the results of the gravimetric determination of sulphur as barium sulphate. The latter results agree closely with the loss on extraction with carbon disulphide after removal of the nitrate.

The differences in results noted above are not readily explained. That both sodium and potassium nitrates are practically insoluble in carbon disulphide was shown by extracting a number of dried samples of each of these nitrates with this solvent, losses of only 0.01 to 0.05 per cent being obtained. It was further demonstrated that the small amount of moisture present in the powder samples at the time of the extraction with carbon disulphide was not the cause of the high results of method 2. This was shown by extracting several samples of black powder with carbon disulphide both before and after drying in vacuum desiccators. On correcting all results to the sample in original condition it was found that the loss on extraction was practically the same in both cases. The results are shown in the table following.

Effect of moisture in black powder on extraction with carbon disulphide before removal of nitrate.

[Determinations by C. A. Taylor.]

Sample.	Moisture.		Loss on extraction with carbon disulphide.	
	Original sample.	Desiccated sample.	Original sample.	Desiccated sample.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
E	0.30	....	13.82	13.93
F	.22	....	10.02	9.99
G	.32	....	7.94	7.92

The method adopted by the Bureau of Mines for the analysis of black powder is as follows:

BUREAU OF MINES METHOD OF ANALYSIS.

Moisture is determined by desiccating a 2-gram portion of the 80-mesh sample spread uniformly on a 3-inch watch glass for three days in a sulphuric-acid desiccator. Nitrates are determined by extraction with water, sulphur by extraction with carbon disulphide, and charcoal by weighing the dried insoluble residue. The soluble impurities (sulphates, chlorides, etc.) are determined separately and a direct determination of nitrate made by means of the nitrometer.

In the analysis of black powder, as in the analysis of all other explosives, the Bureau of Mines follows the standard methods outlined in this bulletin except when the presence of unusual constituents renders necessary additional separations or determinations or introduces new difficulties. As these conditions are seldom met in the analysis of the more simple explosives, such as dynamite and gelatin dynamite, but are not infrequently found in connection with short-flame explosives intended for use in coal mining, they will be taken up in a subsequent bulletin, which will consider the analysis of permissible explosives.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall, 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 12. The behavior of nitroglycerin when heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp., 1 pl.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions; report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 24. Mine fires; a preliminary study, by G. S. Rice. 1912. 51 pp.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

TECHNICAL PAPER 29. Training with mine-rescue breathing apparatus, by J. W. Paul. 1912. 16 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.

MINERS' CIRCULAR 11. Accidents from mine cars and locomotives, by L. M. Jones. 1912. 16 pp.

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Bulletin 52

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

IGNITION OF MINE GASES
BY THE FILAMENTS OF
INCANDESCENT LAMPS

BY

H. H. CLARK
AND
L. C. ILSLEY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

First edition, January, 1913.

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IGNITION OF MINE GASES BY THE FILAMENTS OF INCANDESCENT LAMPS.

By H. H. CLARK and L. C. ILSLEY.

INTRODUCTION.

As part of its investigations of the causes of mine accidents and of the safest and most efficient methods of handling electricity underground, the Bureau of Mines undertook a study of the ignition of mine gases by the filaments of electric incandescent lamps. This bulletin describes the investigation in detail and gives a complete record of the results obtained.

PURPOSE OF THE INVESTIGATION.

The investigation was undertaken for the purpose of determining the degree of danger that attends the use of certain specific sizes of incandescent lamps in atmospheres containing inflammable gas. Previous investigators[a] have, to a greater or less extent, been concerned with certain theoretical features of the problem, such as the effect of the temperature and the dimensions of the lamp filaments and the question whether a lamp may ignite gas by the heat of its glowing filament or by the spark that is drawn when the filament is broken. Although these features were considered in the present investigation and are briefly discussed in this bulletin, the principal object of the tests was to determine what sizes of incandescent lamps suitable for mine use would ignite explosive mixtures of mine gas and air, and what were the circumstances most effective in causing such ignition.

GENERAL STATEMENT OF RESULTS.

The results of the investigation may be generally summarized as follows:

The naked carbon filaments of standard lamps, burning at rated voltage, will invariably ignite explosive gaseous mixtures.

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[a] Couriot, H., professor of mining methods, and Meunier, J., professor of chemistry, Central School of Arts and Manufactures, Paris, France; Heise, F., bergassessor, Gelsenkirchen, Westphalia, Germany; Thiem, Dr., engineer, Siemens-Halske Co., Berlin, Germany; Lemaire, Emanuel, professor, University of Louvain, and engineer, Frameries experiment station, Frameries, Belgium; Hauser, M., professor, Madrid School of Mines, Madrid, Spain; Stassart, A., professor, Hainault Mining and Polytechnic School, Hainault, France.

If gas can reach the filaments of standard lamps without breaking the filaments or producing partial combustion within the bulbs, the explosive gaseous mixture is sure to be ignited.

Several sizes of both standard and miniature lamps, when smashed while burning at rated voltage, will ignite gas.

Standard lamps that do not usually ignite explosive gaseous mixtures may do so if the broken pieces of the filament cause a short circuit when the lamps are smashed.

DEFINITIONS OF TERMS.

For convenience in reporting the results of the investigation, certain terms have been used in a somewhat specialized sense. The terms so used are defined below.

STANDARD—MINIATURE.

The lamps tested are referred to in this bulletin as either standard or miniature. Lamps classified as standard are incandescent lamps such as are used for the purposes of general illumination. These lamps were of various voltages, from 50 to 225, and of various candlepowers, from 8 to 50. Lamps classified as miniature are such lamps as are used for portable service. The voltages of these lamps were 1.5 to 6, and the candlepowers 0.2 to 2.0.

CLASS.

The term class is used to include all lamps of approximately equal voltage and candlepower, regardless of the brand of manufacture. Thus an 8-candlepower, 50-volt lamp and a 30-watt, 55-volt lamp are regarded as belonging to the same general class.

IGNITION—EXPLOSION.

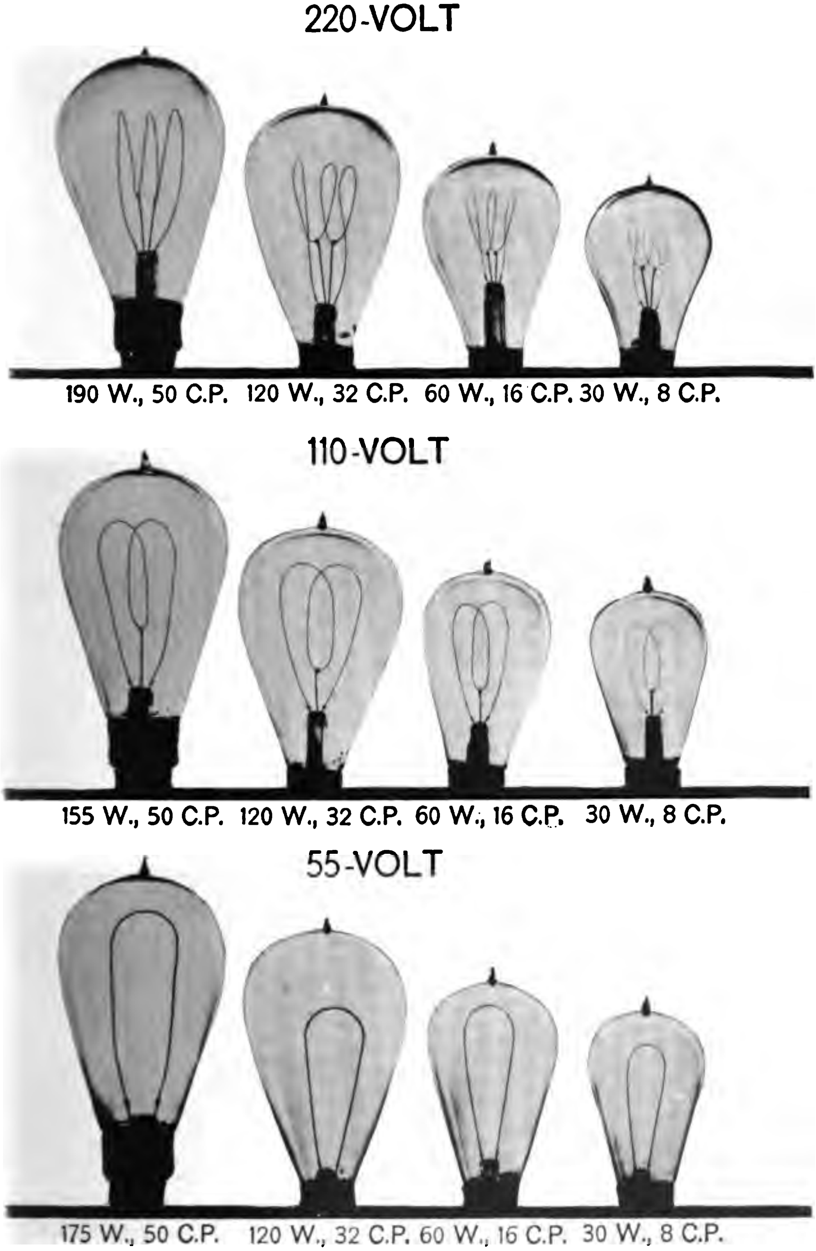
The term ignition is used to denote the act of the filaments in causing the explosive mixtures to take fire. The term explosion is used to refer to the result of an ignition.

SERIES—TEST.

The term series is used to refer to one of the seven principal subdivisions of the investigation in each of which a large number of similar tests was made. The term test refers to a single trial to ignite an explosive mixture with any particular lamp.

LAMP—BULB.

The term lamp is used to refer to the combination of bulb, filament, and base. The term bulb is used to refer to the glass envelope of the filament.



CLASSES OF STANDARD CARBON-FILAMENT LAMPS INVESTIGATED.

GAS.

The term gas, as used hereafter in this bulletin, refers to the natural gas used in the tests, or to a mixture of this gas and air.

DETAILS OF THE INVESTIGATION.

NUMBER AND KINDS OF LAMPS TESTED.

Lamps used in the investigation were supplied without charge to the bureau by certain companies, as follows:

Lamps gratuitously supplied by manufacturers.

Company.	Number of lamps submitted.	Size.	Character of filament.
General Electric Co.	288	Standard	Carbon.
Do.	86	Miniature	Do.
Do.	120	do.	Tungsten.
National Electric Lamp Association	288	Standard	Carbon.
Do.	48	Miniature	Tungsten.
Westinghouse Lamp Co.	192	Standard	Carbon.
Federal Miniature Lamp Co.	52	Miniature	Tungsten.

In addition, the bureau purchased in the open market standard lamps of five different brands.

One thousand one hundred and eighty-eight carbon-filament and 31 tungsten-filament standard lamps, also 42 carbon-filament and 192 tungsten-filament miniature lamps, were used in this investigation, including 125 kinds of lamps differing in candlepower, voltage, or brand. The tables following show the number of each size and the rating of the lamps used. Plate I shows the relative size of the standard lamps used and Plate II, *A*, shows the relative size of the miniature lamps.

TABLE 1.—*Number and rating of standard lamps tested.*

Number used.	Approximate candlepower.	Range of rated wattage.	Rated voltage.	Character of filament.
30	8	28	50	Carbon.
101	8	25-30	55	Do.
10	16	55	50	Do.
92	16	50-60	55	Do.
64	32	100-120	55	Do.
25	50	155-175	55	Do.
125	8	25-30	110	Do.
160	16	50-60	110	Do.
92	32	100-120	110	Do.
8	32	110	127	Do.
30	50	155-175	110	Do.
115	8	28-35	220	Do.
131	16	55-60	220	Do.
149	32	110-120	220	Do.
56	50	175-190	220-225	Do.
11	20	25	110	Tungsten.
20	20	25	220	Do.

Total number of standard lamps used, 1,219.

TABLE 2.—*Number and rating of miniature lamps tested.*

Number used.	Manufacturer's rating.			Character of filament.
	Volts.	Amperes.	Candle-power.	
12	1.5	0.40	0.50	Tungsten.
12	2.0	.23	....	Do.
9	2.0	.40	....	Do.
9	2.0	....	1.00	Do.
12	2.0	.43	....	Do.
5	2.0	.53	....	Do.
5	2.0	.73	....	Do.
23	2.5	.30	1.00	Do.
10	2.5	....	1.00	Do.
44	3.5	.30	1.50	Do.
10	4.0	....	2.00	Do.
5	4.0	.53	....	Do.
10	4.5	....	2.00	Do.
21	5.5	.30	2.00	Do.
5	6.0	.30	....	Do.
7	2.5	....	....	Carbon.
22	3.5	....	....	Do.
13	5.5	....	....	Do

Total number of miniature lamps used, 234.

TEST CONDITIONS AND EQUIPMENT.

CHARACTER OF GAS USED.

Natural gas from the Pittsburgh city mains was used in all tests. The composition of this gas is approximately 82 per cent methane, 16.4 per cent ethane, 1.5 per cent nitrogen, and a trace of carbon dioxide.[a]

The lamps under test were surrounded by gas that was at rest. No tests were made in a current of gas, because gas in motion is not so easily ignited as gas at rest, and it was the intention to make the test conditions as severe as possible.

The lamps were tested in a gas-tight receptacle (Pl. III) filled with a mixture of gas and air. The usual proportion was 8.6 per cent gas to 91.4 per cent air, which is the most explosive combination of the natural gas used and air. The percentage of gas, however, was increased or decreased for some of the tests.

METHODS OF ADMITTING GAS TO BULBS.

The way in which an explosive mixture enters the bulb of an incandescent lamp has an important bearing upon whether the mixture will be ignited by the lamp filament. Accidental entrance to the bulbs of lamps in practical use occurs when the bulbs are completely smashed or the tips are broken from the bulbs.

The smash tests, embraced in series 1, 1-A, 1-B, 1-C, and 1-D, and the tests of series 2, comprising the tip-breaking tests, were made to imitate the two means of entrance indicated. The tests of series 3,

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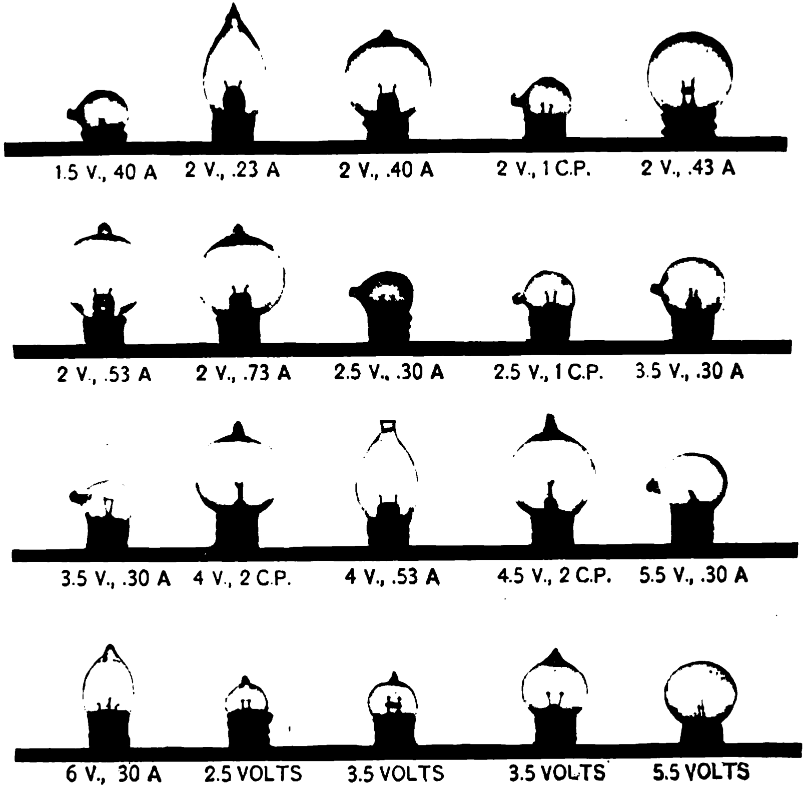
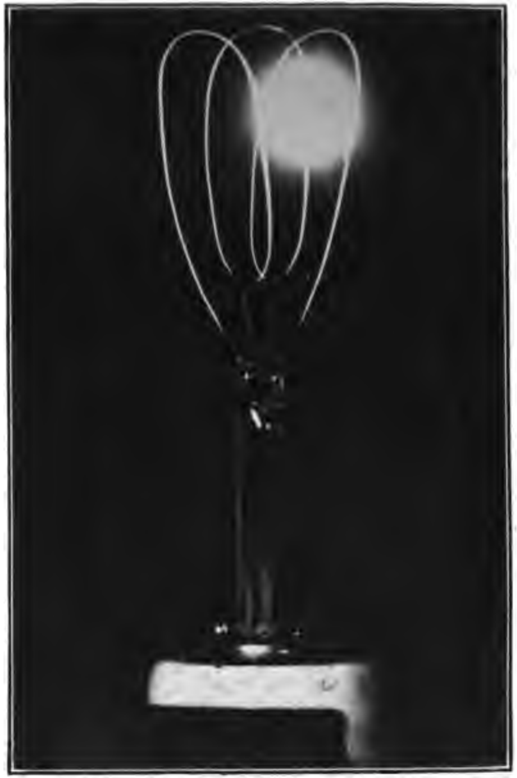
[a] Burrell, G. A., Bull. 15, Bureau of Mines, 1911, p. 66.



A. CLASSES OF MINIATURE LAMPS INVESTIGATED. BEGINNING AT UPPER LEFT-HAND CORNER, THE LAMPS FOLLOW THE ORDER GIVEN IN TABLES 2 AND 6.



B. NAKED FILAMENT OF STANDARD LAMP, SHOWING "HOT SPOT."

embracing the puncture tests, were made to determine what would happen if an explosive mixture should enter a bulb in such a manner as not to impinge directly upon the filament. The tests of series 4, comprising the naked-filament tests, were made to determine the action of filaments burning to extinction in explosive mixtures. The tests of series 1 included five different sets of conditions. The tests of the other series were made under only one set of conditions.

The table following gives the conditions under which each test was made:

TABLE 3.—*Conditions in each series of tests.*

Series No.	Kind of lamps used.	Method of breaking bulbs.	Voltage impressed.	Gas percentage.	Character of current.	Connection of lamps.
1	Standard and miniature.	Smashing	Rated	8.6	Direct	Multiple.
1-A	Standard	do	do	8.6	Alternating	Do.
1-B	do	do	do	8.6	Direct	Series.
1-C	Standard and miniature.	do	do	Various.	do	Multiple.
1-D	do	do	More than rated.	8.6	do	Do.
2	Standard	Breaking tip	Rated	8.6	do	Do.
3	do	Puncture	do	8.6	do	Do.
4	Standard and miniature.	(a)	do [b]	8.6	do	Do.

[a] In each of the series 4 tests the glass bulb was removed and rated voltage was impressed upon the naked filament after it had been surrounded with gas.

[b] It was necessary to use more than rated voltage in order to obtain ignitions from the miniature lamps in the tests of this series.

TESTING EQUIPMENT.

The equipment used in making the tests consisted of the following apparatus: A gas-tight box or gallery (Pls. III and IV) for containing the gaseous mixture in which the lamps were tested; a gas meter for measuring the amount of gas used in the testing mixture; suitable mountings for holding the lamps in proper position for breaking (Pl. V).

Direct current for testing the standard lamps was obtained from a motor-generator set. Alternating current at 60 cycles was taken from a transformer, and direct current for the miniature lamps was supplied by storage or primary batteries.

TESTING GALLERY.

The testing gallery (Pls. III and IV) was a rectangular boiler-iron box, 18 by 18 by 24 inches, provided with a glass door, two observation windows, and a circular opening 13 inches in diameter at the top of the box to relieve the pressure developed by an explosion. This opening was covered by a sheet of paper coated with paraffin and held in place by a heavy iron ring. The electrical connections were brought into the gallery through gas-tight bushings. A sliding rod for breaking the lamps penetrated the side of the gallery through a gas-tight steel bushing.

The gallery was equipped with a small circulating fan directly connected to a $\frac{1}{20}$-horsepower electric motor (Pl. III). The fan intake and the fan discharge were connected to the same end of the gallery. The fan could be entirely isolated from the gallery by means of quick-closing valves. The gas-intake connection was made directly to the gallery near the fan discharge, and at the same point a supply of compressed air was also connected for clearing the gallery of dead gases after each test.

GAS METER.

The gas meter was designed to measure very small quantities of gas and could be read with satisfactory accuracy to 0.001 of a cubic foot. The quantity of gas that was necessary to admit to the gallery in order to obtain a desired percentage of gas in the testing mixture was determined periodically by chemical analysis.[a]

LAMP HOLDERS.

Two different holders were used for mounting the lamps during test. One holder (Pl. V, *A*) was used only in the smash tests for holding the bulbs rigidly at a point where they could be struck squarely by the sliding rod. The other holder (Pl. V, *B*) was used in both the tip-breaking tests and the puncture tests. In the tip-breaking tests the latter holder supported the bulb firmly in position while a spring-actuated arm, which was part of the holder, swept across the tip of the bulb and broke it off clean. In the puncture tests the same holder (Pl. V, *C*) kept the bulb suspended in proper relation to two pointed rods fitted into small indentations made in the bulb by a blowpipe flame. One of the rods was movable. Upon closing a switch, the spring-actuated arm mentioned above swept around and struck the movable rod a blow sufficient to punch a small hole in the bulb. The arm was operated by a spring held in tension by a hooked catch and released by an electromagnet which could be operated from outside the gallery.

CHARACTER OF THE TESTS IN THE DIFFERENT SERIES.

The several methods of testing the lamps are detailed below.

SMASH TESTS.

Tests of the effects of breaking the bulbs were classified under series 1, 1-A, 1-B, 1-C, and 1-D as described below:

SERIES 1, LAMPS ON DIRECT CURRENT.

For the smash tests in which the lamps were on direct current, each lamp was mounted in the holder (Pl. V, *A*) and placed in the

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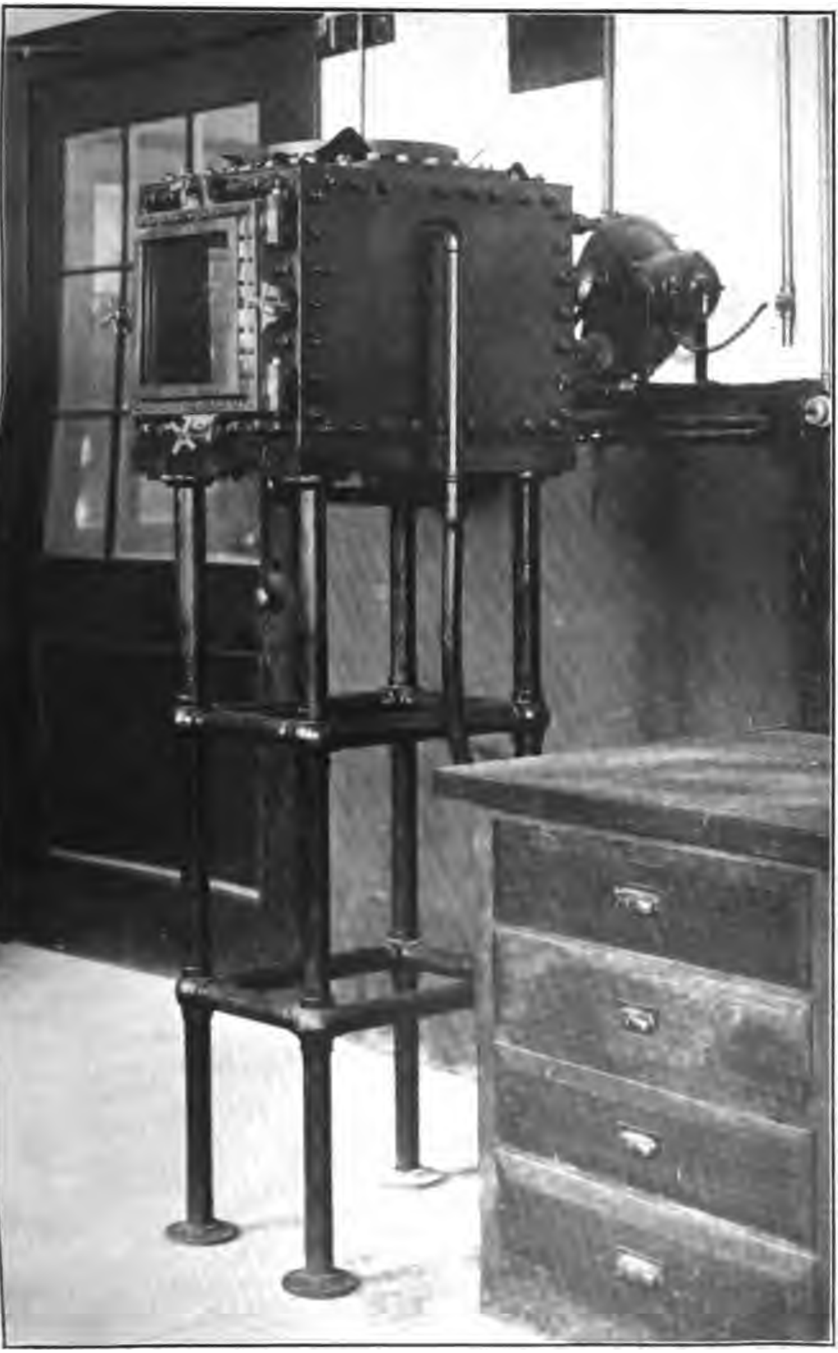
[a] These analyses were made by G. A. Burrell, chemist, of the Bureau of Mines.



TESTING GALLERY, SHOWING CIRCULATING FAN.

gallery. The current consumption of the lamp at rated voltage was measured and the gallery was closed and filled with a mixture of air and 8.6 per cent gas. The lamp was lighted and the bulb was smashed by striking the breaking rod with a hammer (Pl. IV). After all observations had been recorded, the gallery was aired out for the next test. Both miniature and standard lamps were tested in this manner.

SERIES 1–A, LAMPS ON ALTERNATING CURRENT.

The smash tests of series 1–A were identical with those of series 1, except that alternating current was used instead of direct current. The purpose of the series was to determine whether the character of the current had an influence upon the tendency of the lamps to ignite gaseous mixtures. Only standard lamps were tested in this manner.

SERIES 1–B, LAMPS CONNECTED IN SERIES.

The smash tests of series 1–B were identical with those of series 1, except that the lamp under test was in series with one or more similar lamps, the voltage impressed across the series of lamps being of such a value as to give the rated voltage across the terminals of the test lamp. The object of this series of tests was to determine whether the series connection of lamps increases the risk attending the use of such lamps in mines. Only standard lamps were tested in this manner.

SERIES 1–C, GAS PERCENTAGES VARIED.

The tests of series 1–C were also identical with those of series 1, except that the percentages of gas used in the explosive mixture were increased or decreased. The purpose of the tests was to determine whether the lamps would ignite all mixtures containing percentages of gas that were between the explosive limits of the gas. Both miniature and standard lamps were tested in this manner.

SERIES 1–D, VOLTAGE MORE THAN RATED.

In the smash tests of series 1–D a lamp was mounted in the holder and placed in the gallery. The consumption of current by the lamp at a predetermined voltage was measured and the gallery was then closed and filled with gas, the lamp was lighted, and the bulb was smashed by striking the breaking rod with a hammer. The gallery was thoroughly aired after the observations had been recorded. The object of this series of tests was to determine the amount of excess energy that would be required to cause ignition of gas by lamps that did not ignite gas at rated voltage. The results thus obtained provide a means for comparing the relative safety of the different classes of standard lamps when the bulbs are smashed by a direct blow.

gallery. The current consumption of the lamp at rated voltage was measured and the gallery was closed and filled with a mixture of air and 8.6 per cent gas. The lamp was lighted and the bulb was smashed by striking the breaking rod with a hammer (Pl. IV). After all observations had been recorded, the gallery was aired out for the next test. Both miniature and standard lamps were tested in this manner.

SERIES 1–A, LAMPS ON ALTERNATING CURRENT.

The smash tests of series 1–A were identical with those of series 1, except that alternating current was used instead of direct current. The purpose of the series was to determine whether the character of the current had an influence upon the tendency of the lamps to ignite gaseous mixtures. Only standard lamps were tested in this manner.

SERIES 1–B, LAMPS CONNECTED IN SERIES.

The smash tests of series 1–B were identical with those of series 1, except that the lamp under test was in series with one or more similar lamps, the voltage impressed across the series of lamps being of such a value as to give the rated voltage across the terminals of the test lamp. The object of this series of tests was to determine whether the series connection of lamps increases the risk attending the use of such lamps in mines. Only standard lamps were tested in this manner.

SERIES 1–C, GAS PERCENTAGES VARIED.

The tests of series 1–C were also identical with those of series 1, except that the percentages of gas used in the explosive mixture were increased or decreased. The purpose of the tests was to determine whether the lamps would ignite all mixtures containing percentages of gas that were between the explosive limits of the gas. Both miniature and standard lamps were tested in this manner.

SERIES 1–D, VOLTAGE MORE THAN RATED.

In the smash tests of series 1–D a lamp was mounted in the holder and placed in the gallery. The consumption of current by the lamp at a predetermined voltage was measured and the gallery was then closed and filled with gas, the lamp was lighted, and the bulb was smashed by striking the breaking rod with a hammer. The gallery was thoroughly aired after the observations had been recorded. The object of this series of tests was to determine the amount of excess energy that would be required to cause ignition of gas by lamps that did not ignite gas at rated voltage. The results thus obtained provide a means for comparing the relative safety of the different classes of standard lamps when the bulbs are smashed by a direct blow.

GENERAL BEHAVIOR OF LAMPS IN SMASH TESTS.

The general behavior of the lamps in the tests of series 1, 1–A, 1–B, 1–C, and 1–D was the same. With three exceptions, the filaments of standard lamps were broken when the bulbs were smashed, but the miniature-lamp filaments usually remained intact. Ignitions, when they occurred in the tests of standard lamps, seemed to take place almost simultaneously with the blow of the breaking hammer, but in some of the miniature-lamp tests the ignition of gas was delayed until several seconds had elapsed after the bulb had been broken. In most tests the bulb was practically destroyed by the blow. In a few tests the breaking rod merely made a hole in the side of the bulb.

Ignitions from standard lamps, especially from those having a high current consumption, were more violent than ignitions resulting from the miniature-lamp tests. The ignitions obtained when the gas percentages were more or less than 8.6 per cent were less violent than those obtained with 8.6 per cent gas. The diminution of violence was, however, more marked with the lower percentages of gas.

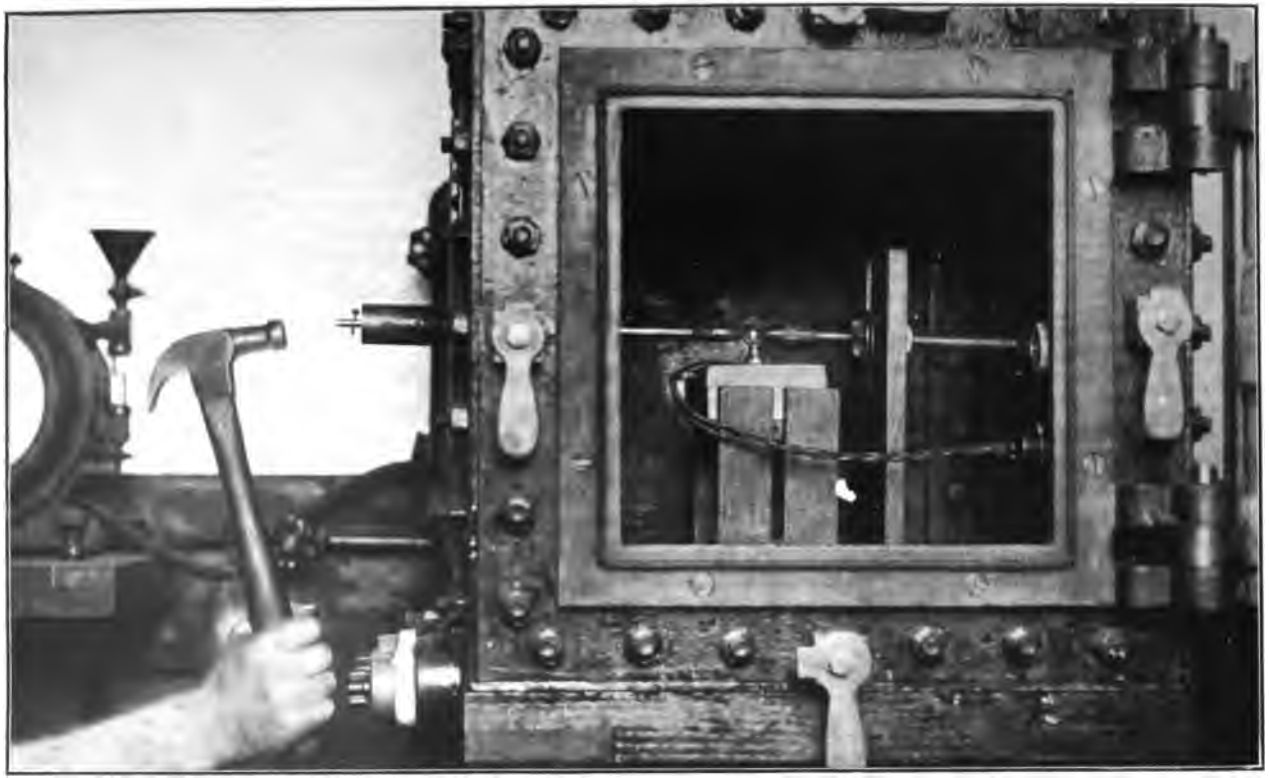
When carbon filaments burned in air or gas the cooling of the filaments caused a decrease in the current consumption. The converse was true of the tungsten filaments. The carbon filaments of the miniature lamps were cooled to such an extent that they burned at a dull red glow, the current consumption being greatly reduced, so that sufficient heat to produce ignition was not developed at the point where the filaments ruptured. The tungsten filaments of the standard lamps were probably broken by the jar from the hammer blow before the gas came in contact with them, but they either retained sufficient heat to ignite the gas when they came in contact with it (as in the case of the 25-watt, 110-volt lamps), or (as in the case of the 25-watt, 220-volt lamps) the pieces of the broken filament short-circuited and thus produced ignition.

SERIES 2, TIP-BREAKING TESTS.

For the series 2 tests a lamp was mounted in the holder (Pl. V, *B*) and placed in the gallery. The current consumption at rated voltage was measured and the gallery was closed and filled with gas. The breaking arm was then released and allowed to sweep across the top of the bulb in such a manner that a part of the tip was broken off. The observations were recorded and the gallery aired. The purpose of these tests was to determine the danger incident to breaking lamps in this manner. Only standard lamps were subjected to this series of tests.

GENERAL BEHAVIOR OF LAMPS IN THE TIP-BREAKING TESTS.

Lamps tested under the conditions of the series 2 tests were affected in three different ways. The lamps tested may be classified, according to the action of the entering gas upon their filaments, as



TESTING GALLERY, SHOWING MINIATURE LAMP IN POSITION FOR BREAKING.

lamps with broken filaments (Pl. VI, *A*), lamps with cooled filaments, and lamps with uncooled filaments. Lamps of the first class never ignited the gas, and require no further comment. Of the lamps with cooled filaments those with the larger filaments usually recovered their temperature without delay and ignited both the gas within the bulb and that surrounding it. Those with the smaller filaments (Pl. VI, *B*) recovered their temperature more slowly, requiring from one to five minutes to ignite the gas. The ignitions from these smaller filaments were generally produced by "hot spots." Plate II, *B*, shows a typical hot spot at the point of rupture. These hot spots occurred at points on the filament where oxidation was more rapid and where the dissipation of energy by the filament was concentrated, as shown by a marked increase in the brilliancy of the filament and subsequent burning at such points. Ignitions caused by hot spots usually occurred just before, or coincident with, the rupture of the filament.

Filaments that were not cooled by the entering gas generally ignited it before the bulbs had filled with gas, thus effecting an ignition not violent enough to destroy the bulb. Part of the products of the ignition remained within the bulb and, upon cooling, became mixed with a fresh supply of incoming gas, and a second ignition weaker than the first was produced. This process continued until the bulb became filled with inert gases. These gases surrounded the burning filament and delayed its oxidation, so that it glowed for a longer period than if surrounded by air. Several consecutive ignitions occurred within the bulb in most tests of this class. Such ignitions were manifested by alternate increase and decrease in the deflection of the ammeter and by the darkening and brightening of the filament. The first two or three ignitions usually produced a hissing noise due to the expulsion of the gases through the small opening in the bulb.

The size of the hole made by the breaking arm was an important factor in producing ignitions. With the larger filaments large holes were more likely to produce ignition than were small ones. Whenever the breaking arm made a sufficiently large hole in the bulb, the entering gas would cool the filament long enough to allow the bulb to become filled with gas. When the inrush of gas had ceased, the filament would at once recover its normal temperature and ignite the gas within and surrounding the bulb. In many such tests the filament continued to glow for several seconds after ignition had taken place.

SERIES 3, PUNCTURE TESTS.

The lamps were prepared for the series 3 tests by indenting the necks of the bulbs at diametrically opposite points by means of a blowpipe flame. The indentations were then covered with pieces of paper the size of a postage stamp. The purpose of the paper was to regulate the size of the hole made by the puncturing rod. The hole made in the paper was usually less than that made through the glass and therefore regulated to some extent the velocity of the entering gas.

The lamp, having been properly prepared, was placed in the holder (Pl. V, *C*) in such a manner that the pointed ends of the puncturing rods entered the indentations in the neck of the bulb. The holder was placed in the gallery and the current consumption of the lamp at rated voltage was measured. The gallery was then closed and filled with gas, the lamp was lighted, and the bulb was punctured. The puncture was caused by a blow from the breaking arm, which in this case was so adjusted as to strike a sliding rod, the pointed end of which was placed in one of the indentations in the lamp. The purpose of these tests was to study the action of the filaments upon gas that entered the bulb in such a way as not to injure the filament.

GENERAL BEHAVIOR OF LAMPS IN THE PUNCTURE TESTS.

The action of the filaments in these tests was similar to that observed in the series 2 tests, except that, owing to the manner in which the gas entered the bulb, fewer filaments were destroyed by the entering gas and consequently more explosions resulted.

SERIES 4, NAKED-FILAMENT TESTS.

The glass was carefully removed from around the filament, and the base, together with the naked filament, was mounted in the holder and placed in the gallery. The gallery was closed and filled with gas. Current[a] was then impressed on the naked filament. The object of the series 4 tests was to observe the action of unbroken filaments burning in a gaseous mixture. Both miniature and standard lamps were tested in this manner.

GENERAL BEHAVIOR OF LAMPS IN THE NAKED-FILAMENT TESTS.

In this series there were among the standard lamps no failures to ignite gas although ignitions were sometimes delayed. The larger filaments ignited the gas practically as soon as current was impressed upon them, smaller filaments ignited the gas after an appreciable interval, and the smallest filaments sometimes burned for several minutes before ignition occurred. In such tests ignition was caused by a hot spot in the filament. As the oxidation of the filament progressed the resistance of certain sections increased to such a

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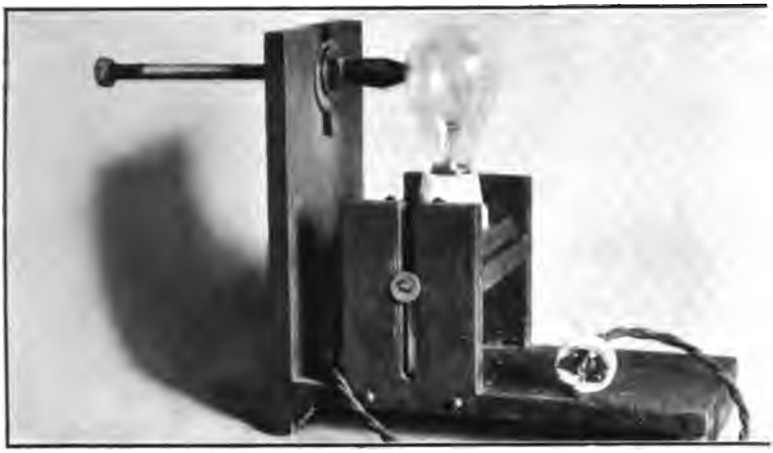
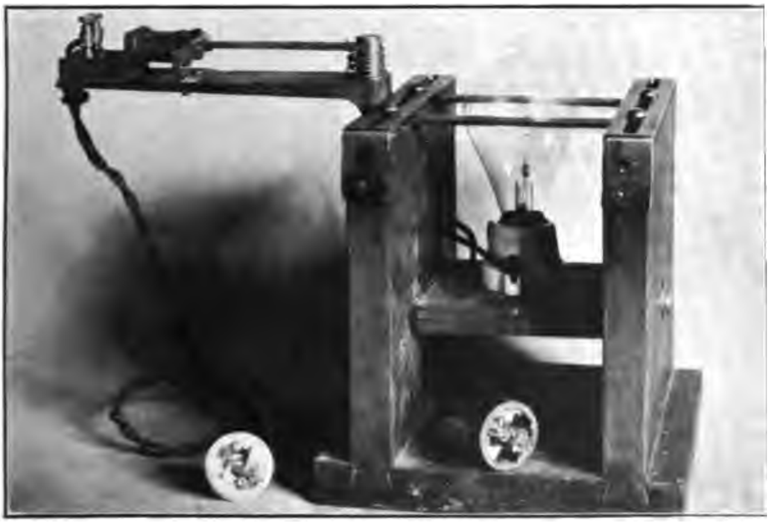
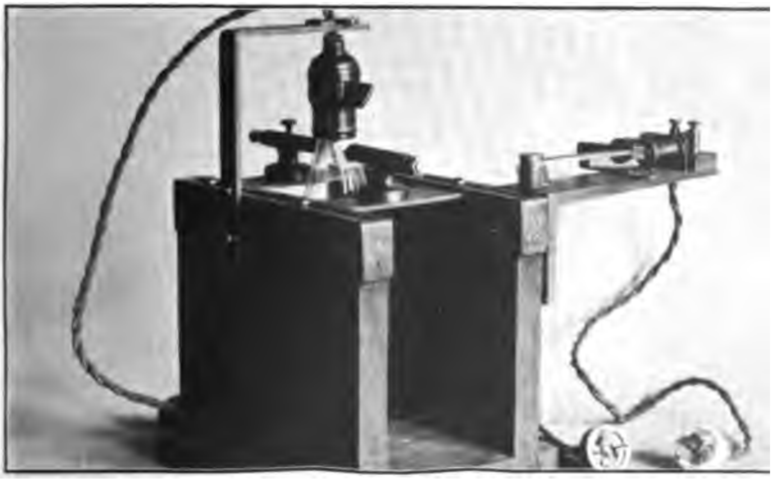
[a] Rated voltage in the case of standard lamps and more than rated voltage in the case of miniature lamps.



A. HOLDER USED IN SMASH TESTS.



B. HOLDER USED IN TIP-BREAKING TESTS



C. HOLDER USED IN PUNCTURE TESTS.

degree that almost all of the energy absorbed by the lamp was concentrated in those sections. The temperature of those sections rose to a degree which, judged by the eye, equalled or exceeded the normal temperature of the filament in a vacuum. In the majority of tests of standard lamps the filaments burned off after the gas had ignited.

EXCEPTIONAL TEST RESULTS.

The results of the investigation as a whole were satisfactorily consistent. Quite as satisfactory, however, were a few tests whose results were the exact opposite of what was to be expected. Some of the exceptional results are mentioned below and are of interest as showing a few of the possible variations in the behavior of the lamps.

Lamp 161, rated 190 watts at 220 volts, and lamps 146 and 171, rated 120 watts at 55 volts, were smashed under series 1 conditions. These were the only standard lamps whose filaments were not broken when the bulbs were smashed. Each lamp gave an immediate ignition when the bulb was broken, the filaments continuing to glow 5 to 20 seconds after the ignition.

Lamp 172, rated 60 watts at 110 volts, was smashed and ignited the gas under series 1 conditions. This was the only ignition resulting from 22 trials, and was probably caused by a short circuit of the filament. This theory is confirmed by the results of subsequent tests made with lamps 617, 646, 706, 800, 897, and 923 in which short circuits were known to have occurred.

Lamp 617, rated 60 watts at 110 volts, was smashed under series 1 conditions. The anchored loop of the filament swung downward and short-circuited the leading-in wires, thus causing ignition of the gas.

Lamp 906, rated 30 watts at 110 volts, was punctured under series 3 conditions. The gas within the bulb was ignited, destroying the bulb but not igniting the gas surrounding it. This was the only test in which the gas surrounding the bulb was not ignited when the explosion within the bulb was sufficiently violent to destroy it. When the bulb was punctured the entering gas cooled the filament to blackness, but it recovered its temperature almost immediately and, after burning with a dull red color for 35 seconds, began to glow more brilliantly. At the end of 47 seconds the gas within the bulb ignited with a sharp, snappy report, completely destroying the bulb, but failing to ignite the gas surrounding it.

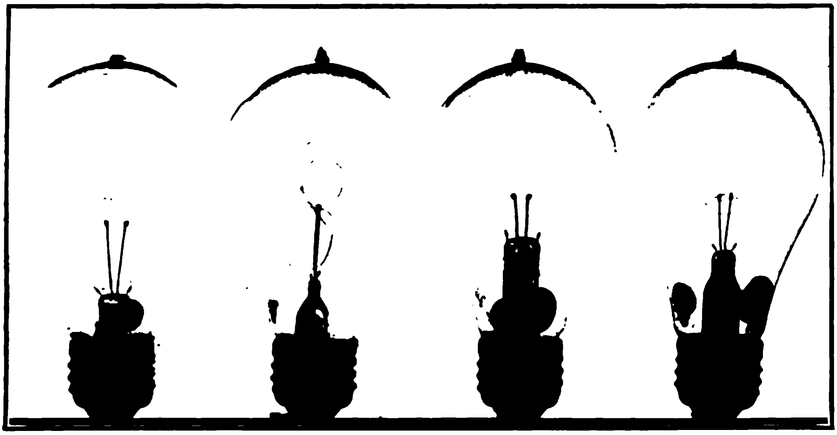
Lamps 672 and 683, rated 120 watts at 220 volts, were tested under series 2 (tips broken) conditions. These tests, although similar to many others of the same series, were noteworthy because of the length of time required for the filaments to oxidize. The filaments of both lamps glowed for more than five minutes before they burned off, and did not ignite the gas in the gallery. The test of lamp 683 was also interesting because 18 distinct ignitions were observed within the bulb. The removal of the tip left a hole $\frac{1}{16}$ inch in diameter. The incoming gas, failing to cool the filament, was ignited before much gas had entered the bulb. The resulting explosion was, therefore, weak and did not injure the bulb. The inflow of gas was momentarily checked, but was almost immediately reestablished by the cooling of the products of combustion within the bulb. The filament, still glowing at nearly normal brilliancy, once more ignited the entering gas and the cycle of events was repeated 17 times in about five seconds with constantly decreasing strength.

Lamp 898, rated 60 watts at 220 volts, when punctured gave a delayed ignition. Lamps of this class usually caused almost immediate ignition when the lamp filaments were not broken by the gas. In the test of this particular lamp the ignition occurred 53 seconds after the bulb had been punctured. The delay of the ignition was probably due to a large opening in the bulb which permitted the entering gas to cool the filament below the ignition temperature of the mixture. The filament did not recover its temperature at once, but burned at a dull red hue, not having sufficient temperature to ignite the gas until the heat became concentrated at a single point. The filament then ignited the gas within the bulb, the explosion destroying the bulb and igniting the surrounding gas.

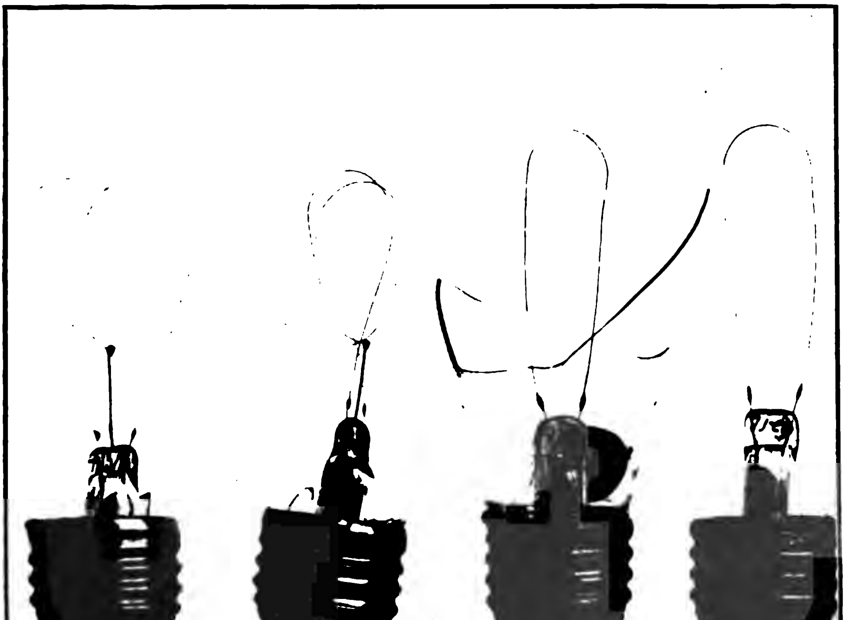
Lamp 780, rated 120 watts at 55 volts, was tested under series 2 (tip broken) conditions, and caused an ignition of gas. This test was one of several in which the filaments continued to burn for several seconds after ignition had taken place. In this particular test ignition occurred almost as soon as the tip had been broken. The resulting explosion destroyed the bulb and ignited the gas surrounding it but did not injure the filament, which burned for 22 seconds before rupturing at one of three hot spots.

Lamp 686, rated 16 candlepower at 110 volts, was tested under series 2 conditions. The tip was so broken that a hole less than one sixty-fourth inch in diameter resulted. The gas entered so slowly that its effect upon the filament was imperceptible. There was no explosion within the bulb, an indication that the gas burned as it entered. The filament developed two hot spots and burned off at one five minutes from the time of breaking the tip.

Lamp 728, rated 30 watts at 55 volts, was tested under series 2 (tip broken) conditions. The filament was slightly cooled as the gas entered, but recovered its temperature and in about two seconds ignited the gas within the bulb, completely destroying it. The filament then burned in the surrounding gas approximately four seconds before ignitng it. The filament was not injured by either igni-



A. LAMPS IN TIP-BREAKING TEST, SHOWING FILAMENTS DISTORTED AND BROKEN BY THE ENTERING GAS.



B. LAMPS IN TIP-BREAKING TEST, SHOWING FILAMENTS THAT BURNED OFF AFTER IGNITING THE GAS.

tion, but burned off at a hot spot nine seconds after the tip had been broken.

Lamp 840, rated 190 watts at 220 volts, was tested under series 2 conditions. The filament was broken off at one leading-in wire by the entering gas. Six flashes were observed within the bulb, which became filled with a smoky vapor. The vapor was later found to have been due to the vaporizing of the substance used to secure the filament to the leading-in wires. The loosened filament made and broke the circuit at this point, causing a slight deflection of the ammeter. The gas within the bulb was not ignited by these flashes.

Lamp 810, rated 120 watts at 110 volts, was tested under series 2 conditions and caused an ignition of both the gas within the bulb and the surrounding gas. This test was exceptional in that a distinct report was heard for each of the two ignitions. Usually when an ignition within the bulb destroyed the bulb the ignition of the surrounding gas followed so quickly that only one report was audible.

Lamp 923, rated 35 watts at 220 volts, ignited the gas when tested under series 3 conditions. When the bulb was punctured there occurred a severe short circuit which, although instantly relieved by the line fuses, registered four times normal current on the ammeter, and burned off the leading-in wires close to the glass.

RESULTS OF STANDARD LAMP TESTS.

TABULATION.

A tabulation of the results of the tests of standard lamps follows.

TABLE 4.—*Number of tests made with standard lamps*[a] *and percentage of ignitions obtained.*

Rating of lamps.[a]	Series 1, 1-A, and 1-B (smash tests, rated voltage—lamps on direct current; lamps on alternating current; lamps in series).		Series 1-C (smash tests—gas percentages varied).		Series 1-D (smash tests—voltage more than rated).[b]		Series 2 (tip-breaking tests).			Series 3 (puncture tests).			Series 4 (naked-filament tests).	
	Number of lamps tested.	Per cent of ignitions.	Number of lamps tested.	Per cent of ignitions.	Number of ignitions.	Minimum per cent of normal wattage, causing ignition.[c]	Number of lamps tested.	Per cent of ignitions.	Per cent of ignitions from unbroken filaments.	Number of lamps tested.	Per cent of ignitions.	Per cent of ignitions from unbroken filaments.	Number of lamps tested.	Per cent of ignitions.
8 candlepower, 50 volts	4	0			2	133.3	5	0	0					
8 candlepower, 55 volts	5	0					5	40	50	4	100	100	4	100
30 watts, 50 volts	4	0			4	146.8	5	40	40					
30 watts, 55 volts	24	8.3			21	127.7	10	30	50	10	80	100		
16 candlepower, 55 volts	16	18.7					3	0	0	2	100	100	4	100
50 watts, 55 volts	4	25												
60 watts, 50 volts	10	80												
60 watts, 55 volts	20	95	28	60.7			15	60	60					
32 candlepower, 55 volts	5	100	1	100			8	75	75	5	60	60	4	100
100 watts, 55 volts	2	100												
120 watts, 55 volts	10	100	24	75			5	60	60					
50 candlepower, 55 volts	7	100												
155–175 watts, 55 volts	8	100					10	80	80					
8 candlepower, 110 volts	8	12.5			9	228	7	0	0	3	100	100	3	100
25 watts, 110 volts	2	0			2	255								
30 watts, 110 volts	12	0			16	214.3	15	13.3	50	15	46.7	100		
16 candlepower, 110 volts	8	0	3	0	10	126.0	8	12.5	16.7	3	100	100	4	100
50 watts, 110 volts	12	8.3			2	106.3								
60 watts, 110 volts	32	9.4	7	14.3	15	109.1	15	13.3	28.6	10	60	100		
32 candlepower, 110 volts	6	50			0		2	0	0	2	100	100	3	100
32 candlepower, 127 volts	8	62.5												
100 watts, 110 volts	4	75					5	60	75					
120 watts, 110 volts	48	50	5	80			15	33.3	38.5					
50 candlepower, 110 volts	7	85.7					5	100	100					
155 watts, 110 volts	4	100					5	40	40					
175 watts, 110 volts	4	100					5	20	25					
8 candlepower, 220 volts	3	0			2	350.0	5	20	100	2	100	100	3	100
35 watts, 220 volts	14	0			9	348.8	20	5	33.3	18	44.4	80		
16 candlepower, 220 volts	5	0			5	206	11	0	0	5	40	100	4	100

60 watts, 220 volts	22	4.5	....	....	24	181.8	15	13.3	33.3	15	66.7	100	....	....
32 candlepower, 220 volts	7	0	....	....	9	120.2	3	33.3	50	3	66.7	66.7	4	100
120 watts, 220 volts	44	2.3	....	....	21	116.8	20	20	22.2	10	80	80	....	....
50 candlepower, 220-225 volts	20	80	....	....	....	....	6	66.7	80.0	2	100	100	2	100
190 watts, 220 volts	16	68.7	....	....	....	....	10	50	62.5	....	....	....	....	....
25 watts, 110 volts	7	85.7	....	....	....	....	4	75	75	....	....	....	....	....
25 watts, 220 volts	14	28.6	....	....	....	....	6	0	0	....	....	....	....	....

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[a] The manufacturers' ratings are given. The approximate candlepower of any standard lamp rated in watts may be ascertained by dividing the wattage rating by 3.5 in the case of carbon-filament lamps and by 1.25 in the case of tungsten-filament lamps. All lamps tested were carbon-filament lamps except those represented by the last two items, which were tungsten-filament lamps.

[b] Additional results are given in Table 6.

[c] Normal wattage as here given is the wattage of the lamp at rated voltage as distinguished from the rated wattage of the lamp.

DISCUSSION.

The results of the tests of the standard lamps were satisfactory in that positive results were obtained in almost every case. The purpose of the tests was to determine whether certain specific sizes of incandescent lamps would when broken ignite explosive mixtures of gas and air. The results obtained showed that gaseous mixtures could be ignited by all the classes of standard lamps tested and also by all the classes of miniature lamps that gave sufficient light to be of commercial value. Although some classes of lamps gave comparatively few ignitions, the unsafe character of such lamps was indicated by even a single ignition under conditions that might exist in actual practice.

SMASH TESTS (SERIES 1).

Series 1 tests included tests of both standard and miniature lamps. In table 4 the results of series 1–A and 1–B are combined with those of series 1, as the behavior of the lamps was the same in all three series.

In the tests of series 1–A, made with alternating current, 25 ignitions were obtained from 80 trials, as compared to 26 ignitions from 80 trials in the tests of series 1 made with direct current. In the tests of series 1–B, made with series-connected lamps, 11 ignitions were obtained from 50 trials, as compared to 14 ignitions from 50 trials made with similar lamps connected in multiple (series 1).

The results presented in table 4 demonstrate that the standard lamps that ignite gas least readily are those of low candlepower and high voltage. The only lamps that, in some brand, did not ignite gas were those of the 8-candlepower, 220-volt class. Lamps of the 16-candlepower, 220-volt and 32-candlepower, 220-volt classes failed to ignite gas in some brands, but gave ignition in others.

There is a seeming lack of uniformity in the number of lamps of each rating tested. This is due to the fact that the lamps were tested by general classes rather than by brands or ratings. As an additional reason, the tests of series 1–C and 1–D showed so conclusively the characteristics of certain sizes of lamps that it was not thought necessary to multiply repetitions of the series 1 tests. Not less than 80 smash tests of one form or another were made of each general class of lamp concerning whose ability to ignite gas there was any doubt.

Standard incandescent lamps for underground use are usually 16-candlepower, 110 to 250 volt lamps. Sixty-two carbon lamps and 7 tungsten lamps of the 16-candlepower, 110-volt class were tested by direct smashing while burning at rated voltage. Five of the carbon and 6 of the tungsten lamps ignited the gas. Twenty-seven carbon lamps and 14 tungsten lamps of the 16-candlepower, 220-volt class were tested by direct smashing while burning at rated voltage. One of the carbon lamps and 4 of the tungsten lamps ignited the gas. The carbon lamp produced ignition by the short-circuiting of its filament.

The percentage of ignitions given by the several classes of lamps is graphically shown in figure 1. The figure indicates that 55-volt and 110-volt lamps of all candlepowers ignited gas under the conditions of the series 1 tests, that 32 and 50 candlepower, 55-volt lamps invariably ignited the gas, that the 8-candlepower, 220-volt lamps gave no ignitions, and that in general the percentage of ignitions obtained from lamps of a given candlepower decreased as the voltage increased.

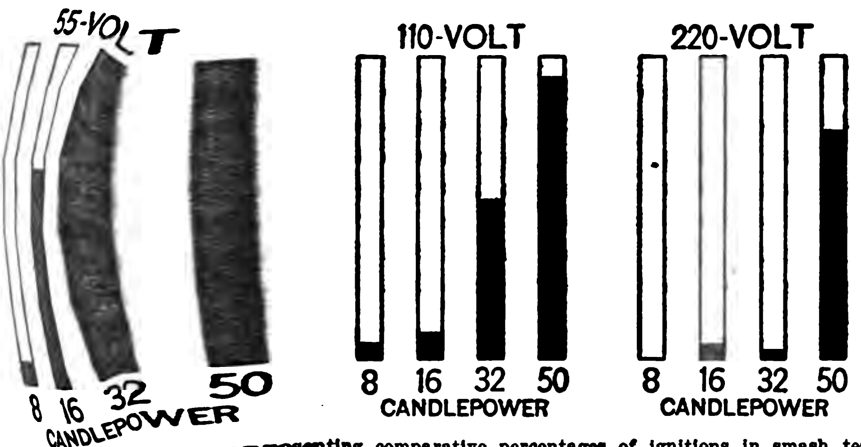

FIGURE 1.—Diagram representing comparative percentages of ignitions in smash tests. Shaded parts represent ignitions; unshaded parts represent failures to ignite.

SMASH TESTS (SERIES 1–A AND 1–B).

Series 1–A and 1–B tests were made with standard lamps only. As stated above the behavior of the lamps was the same as in the tests of series 1.

SMASH TESTS (SERIES 1–C).

The tests of series 1–C were made with both standard and miniature lamps. The results showed that any standard or miniature lamp that would cause ignition of gas in the most explosive mixture would, under similar conditions, ignite mixtures containing from 5 to 11.5 per cent of gas.

None of the lamps ignited mixtures containing more than 12 or less than 5 per cent of gas.

SMASH TESTS (SERIES 1–D).

Series 1–D tests were made with both standard and miniature lamps.

The tests of standard lamps were made for two purposes, first to confirm by positive results the negative results of the series 1 tests, and second to btain a means of comparing the relative safety of such lamps as did not cause ignition in the series 1 tests.

The tests achieved the purpose for which they were undertaken. Lamps that gave negative results in the tests of series 1 gave no ignitions in the series 1–D tests until their energy consumption had been increased by at least 26 per cent (see table 4, 16-candlepower, 110-volt lamp).

Table 4 gives, for each brand of standard lamps tested, the number of ignitions and the percentage of normal wattage at which ignition took place. Table 5 gives similar information for each general class of lamp. The figures given in the fifth column of table 5 provide a means of comparing the relative abilities of the lamps to ignite the gas when the lamps are broken by a direct blow while under rated-voltage conditions. A lamp that causes ignition only when its filament is radiating 3.5 times its normal energy is obviously less likely to ignite gas under normal conditions than a lamp that invariably causes ignition when radiating only 30 per cent more than its normal energy.

TABLE 5.—*Summary of results of tests in series 1–D.*

Approximate rating of lamps.			Number of ignitions.	Percentage of normal wattage causing ignitions.		
Candlepower.	Watts.	Volts.		Minimum.[a]	Average minimum.[b]	Average.[c]
8	30	55	27	128	135	142
8	25–30	110	24	214	232	239
16	50–60	110	27	[d] 106	119	126
8	35	220	11	349	364	365
16	60	220	27	182	199	205
32	120	220	30	117	126	132

[a] Minimum percentage of normal wattage (See footnote, table 4) at which an ignition was obtained from any brand of lamp.

[b] Average minimum percentage of normal wattage for all brands.

[c] Average percentage of normal wattage for all tests giving an ignition.

[d] This brand of lamp gave ignitions at normal wattage in 8.3 per cent of the series 1 tests (see table 4, 50-watt, 110-volt lamp).

TIP-BREAKING TESTS (SERIES 2).

The tests of series 2 were made with standard lamps only. The results of the tests showed that practically every class of standard lamps will ignite gas if the tips are removed in a certain way. The size of the hole left by the removal of the tip has an important bearing upon whether or not ignition will occur. Small filaments are most likely to ignite when the hole is small; the reverse is true with large filaments. There are three conditions that may exist after the tip has been removed:

The filament may be distorted and broken by the entering gas (Pl. VI, *A*); the filament may remain intact but be cooled by the entering gas below the ignition point of the gas, recovering its temperature later and burning off after igniting the gas (Pl. VI, *B*); the filament may ignite the gas as it enters, thus producing a partial explosion that temporarily checks the entrance of gas and fills the bulb with the products of combustion.

These conditions are stated in the order of the violence of the gas entrance. The first and last are at either extreme and produce no ignition. The second condition which depends upon the proper relation of filament diameter to gas-entrance velocity is the only one that causes ignitions, but does so invariably. Wherever in table 4 less than 100 per cent of ignitions from unbroken filaments is reported, the third condition prevailed in some of the tests. Whereever the percentage of ignitions does not agree with the percentage of ignitions from unbroken filaments, the first condition prevailed in some of the tests.

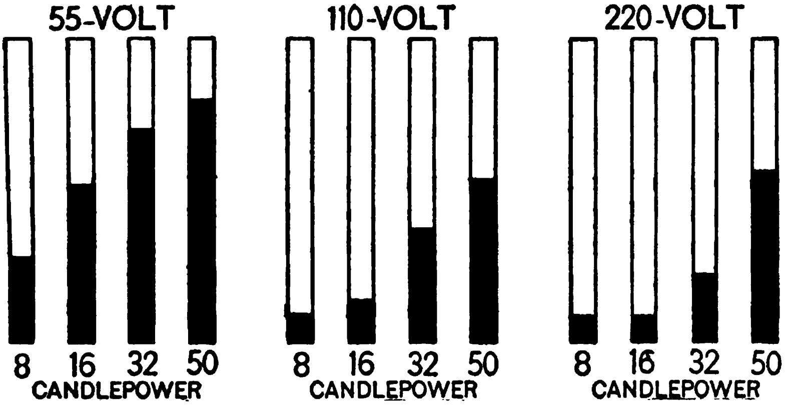

FIGURE 2.—Diagram representing comparative percentages of ignitions in tip-breaking tests. Shaded parts represent ignitions; unshaded parts represent failures to ignite.

Figure 2 shows graphically the percentage of ignitions obtained from the various classes of lamps. The figure shows that the percentage of ignitions increased as the candlepower rating increased and decreased as the voltage rating increased, and that although no class of lamps gave 100 per cent of ignitions, all classes produced some ignitions. Although the average percentage of ignitions in the tests of series 2 is less than that in the tests of series 1, the former tests proved to be the more severe because they showed that every class of lamp could cause ignition. The tip-breaking and the smash tests are both practical. In the majority of underground lighting systems, the tip of the bulb is the most exposed part of the lamp and lamps are often destroyed by having their tips broken off.

PUNCTURE TESTS (SERIES 3).

The tests of series 3, made with standard lamps only, were similar in character to those of series 2, the principal differences being that the gas entered through larger holes and did not impinge directly upon the filaments. Under these conditions the filaments were greatly cooled, but were not broken. As compared to the tests of series 2, the percentage of unbroken filaments was 1.45 times as great. The cooling of the filaments is evidenced by the high percentage of ignitions from unbroken filaments, which was 2.5 times as great as in the tests of series 2. The severity of the conditions is shown by the fact that the percentage of ignitions was 3.6 times as great as in the series 2 tests.

NAKED-FILAMENT TESTS (SERIES 4).

The tests of series 4 were made with both standard and miniature lamps. They showed conclusively that any of the standard lamp filaments burning in an explosive mixture of gas will eventually ignite it. This fact is confirmed by some of the series 3 results, the conditions in the latter series being similar in some tests to the conditions in the series 4 tests.

RESULTS OF MINIATURE-LAMP TESTS.

TABULATION.

A tabulation of the general results of the tests of miniature lamps follows:

TABLE 6.—*Number of tests made with miniature lamps,*[a] *and percentage of ignitions obtained.*

Manufacturer's rating.			Number of lamps tested.	Series No.	Conditions of test.			Results of test.		
Candlepower.	Volts.	Amperes.			Percentage of rated voltage.[b]	Gas percentage.	Bulb broken by—	Number of ignitions.	Percentage of ignitions.	Minimum percentage of rated voltage giving an ignition.
0.5	1.5	0.40	10	1-D	132.7	8.6	Smashing...	1	10.0	132.7
.5	1.5	.40	2	4	138.7	8.6	(c)	1	50.0	138.7
....	2.0	.23	9	1-D	120.0	8.6	Smashing...	3	33.3	110.0
....	2.0	.23	3	1-D	148.5	8.6	(c)	1	33.3	148.5
....	2.0	.40	4	1	100.0	8.6	Smashing...	1	25.0	100.0
....	2.0	.40	5	1-D	108.8	8.6	.....do.......	2	40.0	107.5
1.0	2.0	......	9	1	100.0	8.6	.....do.......	7	77.8	95.0
....	2.0	.43	8	1	96.7	8.6	.....do.......	3	37.5	95.5
....	2.0	.43	4	1-D	108.0	8.6	.....do.......	4	100.0	106.0
....	2.0	.53	1	1	98.5	8.6	.....do.......	1	100.0	98.5
....	2.0	.53	4	1-D	102.8	8.6	.....do.......	3	75.0	101.0
....	2.0	.73	5	1	94.5	8.6	.....do.......	3	60.0	90.0
1.0	2.5	.30	11	1	100.0	8.6	.....do.......	7	63.6	100.0
1.0	2.5	.30	12	1-C	100.0	5 to 6 and 11 to 11.5	.....do.......	4	33.3	100.0
1.0	2.5	......	10	1	100.0	8.6	.....do.......	3	30.0	100.0
1.5	3.5	.30	23	1	99.2	8.6	.....do.......	16	69.6	98.6
1.5	3.5	.30	21	1-C	100.0	5 to 6 and 11 to 12.5	.....do.......	12	57.1	100.0
2.0	4.0	......	10	1	82.2	8.6	.....do.......	7	70.0	70.0
....	4.0	.53	5	1	94.9	8.6	.....do.......	5	100.0	91.3
2.0	4.5	......	10	1	85.3	8.6	.....do.......	7	70.0	71.1
2.0	5.5	.30	9	1	98.8	8.6	.....do.......	6	66.7	78.0
2.0	5.5	.30	12	1-C	100.0	5 to 7 and 11.5 to 12	.....do.......	11	91.7	100.0
....	6.0	.30	5	1	88.2	8.6	.....do.......	5	100.0	88.0
(d)	2.5	(d)	2	1-D	[e]108.0	8.6	.....do.......	0	....	....
(d)	2.5	(d)	5	4	168.0	8.6	(c)	1	20.0	168.0
(f)	3.5	(f)	10	1	[e]99.2	8.6	Smashing...	0	....	....
(f)	3.5	(f)	7	1-D	137.1	8.6	.....do.......	2	28.6	137.1
(f)	3.5	(f)	5	4	142.9	8.6	(c)	2	40.0	142.9
(g)	5.5	(g)	4	1	[e]98.2	8.6	Smashing...	0	....	....
(g)	5.5	(g)	6	1-D	105.2	8.6	.....do.......	4	66.7	103.8
(g)	5.5	(g)	3	4	101.5	8.6	(c)	1	33.3	101.5

[a] The lamps had tungsten filaments, except those represented by the last eight items, which were carbon-filament lamps.

[b] The values given in this column are the average values of the voltage impressed upon such lamps as caused ignition.

[c] Naked-filament tests.

[d] These lamps had no current or candlepower rating, but consumed in test about 0.20 ampere.

[e] Average voltage impressed upon the lamps tested, whether causing ignition or not.

[f] These lamps had no current or candlepower rating, but consumed in test about 0.35 ampere.

[g] These lamps had no current or candlepower rating, but consumed in test about 0.30 ampere.

DISCUSSION.

Miniature lamps can not be divided into as distinct classes as are standard lamps, because the demands of the service to which miniature lamps are put are quite different. On account of the desirability of using as light a battery as possible, miniature lamps are often operated at higher temperatures than standard lamps, with a proportionately increased efficiency and decreased length of life. A single lamp may be variously rated according to the needs of the purchaser as to the candlepower, voltage, current consumption, or life.

Another variable that affects the performance of miniature lamps is the voltage of the battery with which the lamps are used. There are no standard voltages for this class of service. For portable lights there is available almost any voltage from 1.3 to 7. These voltages are not constant during the length of life of the battery or charge, and at the beginning lamps must be used at overvoltage in order to give a satisfactory average performance. These facts should be borne in mind while examining table 6, which summarizes the results obtained from the tests of miniature lamps.

The results presented in table 6 show that none of the carbon-filament lamps ignited gas under the conditions of the series 1 (smash) tests. In fact, no ignitions from carbon-filament lamps burning at rated voltage were obtained in the tests of any of the series. An ignition with a potential 4 per cent above rated voltage was obtained from a carbon lamp of the 5.5-volt class under the conditions of the series 1–D tests. Carbon lamps of all the other classes gave little light and would be of little practical use in mines.

Fifteen classes of tungsten lamps were tested under series 1 conditions. All ignited gas except the lamps of the 2-volt, 0.23-ampere class, and the lamps of the 1.5-volt, 0.4-ampere class. The former gave an ignition in a later test with a 20 per cent overvoltage, and the latter with a 33 per cent overvoltage. Both of these lamps gave about 0.5 candlepower.

These tests showed that it is quite probable that any miniature lamp that gives enough light to be of practical use in a mine will ignite explosive mixtures of gas and air if the bulb is so broken that the filament is not injured.

Table 6 shows the results obtained from the smash tests, under series 1–D conditions, of nine classes of miniature lamps. The number of ignitions has been related to the impressed voltage in percentage of rated voltage instead of to the energy consumption in percentage of normal wattage, as with the standard lamps. This was done because the series 1–D tests were of an arbitrary nature so far as standard lamps were concerned, and were made principally to determine the " factor of safety " of the various lamps. For this purpose the wattage absorbed by the filament is the best indication, as it governs the temperature of the filament and hence the quantity of stored heat.

In the case of the miniature lamps, however, the tests were practical, as these lamps are often purposely used at greater than rated voltage, and may be used, through accident or ignorance, at voltages much higher than those at which the lamps are rated. The relative danger under such conditions was better shown by the increase in voltage than by the increase in wattage. The maximum overvoltage required to give ignition in these tests was approximately 37 per cent for carbon lamps and 33 per cent for tungsten lamps.

Only a few miniature lamps were tested under series 4 (naked filament) conditions. The lamps tested were of a class that had not caused ignition when smashed at rated voltage. Only one of these lamps gave an ignition at rated voltage under the series 4 conditions.

The tests showed that the naked filaments of miniature lamps will not invariably cause ignition, as the naked standard filaments do, when burned to extinction in explosive mixtures.

IMMEDIATE CAUSE OF IGNITION.

It was not regarded as absolutely essential to the value of the investigation here reported that the specific cause of ignition of the gas be determined. Other investigators, however, have been much interested in this phase; consequently, certain observations are reported herein that bear upon the question of whether the ignition is caused by the glowing filament alone or by the spark that occurs when the filament is ruptured.

That glowing filaments may ignite gas seems to be proved by the fact that in 58 tests in which the gas was ignited the filaments continued to glow 2 to 59 seconds after ignition had taken place.

The tests did not prove so conclusively that the spark that occurs when the filaments are broken is not the cause of gas ignition, although the following evidence seems to show that the unassisted spark can not ignite gas: Fifty tests made upon 50, 60, and 120 watt lamps, each of 110 volts, showed a greater percentage of ignitions when the lamps were connected in multiple than when they were connected in series, although the breaking spark was drawn at 110 volts with the lamps in multiple as against 550 volts with the lamps in series.

By breaking a noninductive 550-volt circuit between a steel contact and a carbon contact, it was found that when the current exceeded 0.15 ampere an ignition was always obtained when the circuit was opened. Yet 10 tests made with five 110-volt lamps connected in series across 550 volts produced no ignition, although the filament of the tested lamp carried one-half an ampere, and the spark must have been drawn at 550 volts. Neither were ignitions obtained from 11 similar tests made with lamps carrying approximately 1 ampere.

The authors believe that the spark that is drawn when a lamp filament is broken is to a great extent "blown out" by the entering current of gas. To prove this assumption, a 50-watt, 55-volt naked filament was connected in series with noninductive resistance and 0.5

ampere (one-half normal current) at 110 volts was passed through the circuit. The filament was then broken by gradual pressure, which distorted it until it snapped off. Five ignitions were obtained from six tests made in this way. Similar lamps were then connected in series with noninductive resistance across 550 volts, and the filaments were disrupted by smashing the lamp bulbs. Five tests were made, three with a current of 0.6 ampere and two with a current of 0.7 ampere. No ignition was obtained in any of the five trials, although the current was 20 to 40 per cent greater and the voltage 400 per cent greater than in the five tests that gave ignitions with the naked filaments. It is therefore manifest that the inrushing gas has a quenching effect upon the spark.

Five tests were then made by connecting a 175-watt, 55-volt lamp (normal current 3.5 amperes) in series with a noninductive resistance of such value that 2.25 amperes flowed through the filament when 550 volts was impressed across the lamp and resistance. The lamp was surrounded with gas and smashed while carrying this current. No ignition resulted from five trials, although the current broken was greater and the voltage ten times as great as in the case of lamps[a] that invariably produced ignitions when broken while burning under normal conditions.

It is manifest that the spark alone did not cause these ignitions, if ignition could not be caused by a similar spark with ten times the voltage behind it.

AUTHORS' THEORY OF THE IGNITION PHENOMENON.

The authors are inclined to believe that the likelihood of gas[b] ignition by standard carbon-filament lamps is a function of the cross section of the filaments. The filaments of 24 different types of standard lamps were measured[c] and the cross sections of the filaments were compared to their tendency to ignite gas, as expressed in percentage of ignitions obtained in a given number of trials. All filaments having a cross section of 0.000177 square centimeter or less failed to ignite gas in the series 1 tests. All filaments having a cross section of 0.000234 square centimeter or more invariably ignited gas under the conditions of the series 1 tests; filaments having a cross section of 0.000194 square centimeter ignited gas in 50 per cent of the trials; and filaments having a cross section of 0.000215 square centimeter ignited gas in 83 per cent of the trials. It is true that a similar relation existed between the current flowing in the filaments and the percentage of ignitions that they gave, but the authors do not regard this relation as significant, because they believe that the spark that is drawn when a filament is broken is not responsible for the ignition of gas.

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[a] See table 4, 32-candlepower, 55-volt lamps; 100-watt, 55-volt lamps; and 120-watt, 55-volt lamps.

[b] See definition on p. 7.

[c] These measurements were made with a microscope by Reinhardt Thiessen, assistant chemist of the Bureau of Mines. Three sets of readings were taken, one with a micrometer eyepiece and two with a camera lucida.

If the bulb of a glowing incandescent lamp is smashed while surrounded by an explosive mixture, and if the filament is not broken by the jar of the blow, the filament is first cooled by the inrushing mixture and then broken by it. Of course the cooling and the breaking are almost simultaneous, but the authors believe that ignition, if it occurs, takes place during the period of cooling and before the filament is broken.

If this hypothesis is correct, there are two reasons why large filaments ignite gas more readily than smaller ones: First, the temperature of the larger filaments will not be so greatly reduced before they are broken; and, second, the larger filaments will not so quickly succumb to the breaking action of the inrushing gas.

The authors are not yet certain whether the ignition of gas by standard tungsten lamps is caused by the normal heat of the filaments or by abnormal temperatures resulting from a short circuit of the filament.

It is probable that miniature lamps ignite gas by virtue of their glowing filaments, as the sparks produced when the filaments are broken are small, and in many tests the filaments were observed to glow after ignition had taken place.

SUMMARY OF DEDUCTIONS.

The investigation showed that the naked filaments of all standard lamps, energized at rated voltage, will ignite gas (the explosive gaseous mixture used); that all classes of standard carbon lamps will sometimes ignite gas when the tips of the bulbs are broken off in the presence of those mixtures; that the filament temperature of all classes of standard lamps and of all but one class of miniature lamps can be increased to such a degree that the lamps when smashed will ignite gas; that several classes of both standard and miniature lamps when smashed while burning at rated voltage will invariably ignite gas; that certain other classes of both standard and miniature lamps under the circumstances last mentioned will not usually ignite gas.

Based upon the results of the investigation, the table following gives deductions as to the probability of igniting gas by each class of lamp examined.

TABLE 7.—*Probability of gas ignition at rated voltage by each class of lamps tested.*[a]

Classification of lamp.				Condition of lamp.	Ignition of gas.
Size.	Character of filament.	Approximate candlepower.	Approximate voltage.		
Standard...	Carbon....	50	55	Bulb completely smashed...	Certain.
Do.....	...do......	32	55	.....do.....................	Do.
Do.....	...do......	50	110	.....do.....................	Almost certain.
Do.....	...do......	50	220	.....do.....................	Do.
Do.....	...do......	16	55	.....do.....................	Do.
Do.....	...do......	32	110	.....do.....................	Frequent.
Do.....	...do......	8	55	.....do.....................	Occasional.
Do.....	...do......	16	110	.....do.....................	Do.
Do.....	...do......	32	220	.....do.....................	Rare.
Do.....	...do......	16	220	.....do.....................	Do.
Do.....	...do......	8	110	.....do.....................	Do.
Do.....	...do......	8	220	.....do.....................	Unlikely.[b]
Do.....	...do......	50	55	Tip of bulb broken off.......	Almost certain.
Do.....	...do......	32	55	.....do.....................	Do.
Do.....	...do......	50	110	.....do.....................	Frequent.
Do.....	...do......	50	220	.....do.....................	Do.
Do.....	...do......	16	55	.....do.....................	Do.
Do.....	...do......	32	110	.....do.....................	Do.
Do.....	...do......	8	55	.....do.....................	Do.
Do.....	...do......	32	220	.....do.....................	Occasional.
Do.....	...do......	16	110	.....do.....................	Do.
Do.....	...do......	8	110	.....do.....................	Do.
Do.....	...do......	16	220	.....do.....................	Do.
Do.....	...do......	8	220	.....do.....................	Do.
Do.....	Tungsten.	20	110	Bulb completely smashed...	Almost certain.
Do.....	...do......	20	220	.....do.....................	Frequent.
Do.....	...do......	20	110	Tip of bulb broken off.......	Almost certain.
Do.....	...do......	20	220	.....do.....................	Unlikely.[b]
Miniature..	...do......	2.0	4-6	Bulb completely smashed...	Certain.
Do.....	...do......	1.5	2-3.5	.....do.....................	Almost certain.
Do.....	...do......	1.0	2-2.5	.....do.....................	Frequent.
Do.....	...do......	.5	1.5-2	.....do.....................	Unlikely.

[a] The results of tests of the miniature carbon-filament lamps are not included in this table because those lamps were rated in voltage only and hence their behavior could not be used as a standard of comparison.

[b] No ignitions were obtained in any of the tests of this lamp made under the condition stated.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 4 pls.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1912. 50 pp. 3 pls.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 12. The behavior of nitroglycerin when heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp., 1 pl.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions; report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.

MINERS' CIRCULAR 11. Accidents from mine cars and locomotives, by L. M. Jones. 1912. 16 pp.

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Bulletin 53 Mineral Technology 1

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

MINING AND TREATMENT OF FELDSPAR AND KAOLIN

IN THE SOUTHERN APPALACHIAN REGION

BY

A. S. WATTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

First edition. June, 1913.

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PREFACE.

Apart from the fuel and metal-mining industries of the United States, no one of the various branches of mineral technology is more important to our domestic economy than are the ceramic arts. Aside from the manufacture of crockery, household china, and bric-a-brac, the development of the white-ware industry with reference to the production of plumbers' sundries, tile, and faced brick is of the utmost importance to the country. Its development will have an increasing influence on fireproof construction and proper sanitation, and therefore will lessen our unparalleled fire losses and help conserve the public health.

According to statistics compiled by the United States Bureau of Foreign and Domestic Commerce, there were imported into the United States during the 12 months ending June 30, 1912, china and porcelain valued at $9,515,851. In addition, 235,438 tons of kaolin or China clay were brought in to be manufactured into various forms of white ware. This kaolin displaced a like amount of domestic raw material, which, if properly handled, has no superior.

The kaolin, feldspar, and quartz industry of the United States is one of small operators, few of the mines being on a scale that warrants the employment of expert technical control. The extensive reduction of existing waste, the preparation of a standard product, and the marketing of guaranteed material become possible only when the losses are understood and the just requirements of the purchaser are realized. This bulletin has to do with the primary source of material used in the manufacture of white ware, and especially with this material as it occurs in the southern Appalachian region.

Investigations of kaolin, feldspar, and quartz were undertaken by the Bureau of Mines with the following objects in view:

(*a*) To discover the wastes and the possible by-products incident to production and point out methods for their recovery;

(*b*) To encourage efficiency in mining and treatment, with the hope of enlarging the output and of increasing the quality and uniformity of the product;

(*c*) To study the hazards of the industry, both as regards accident risks and health conditions;

(*d*) To determine by actual tests the physical constants and the general classification of the material from the various working deposits;

(*e*) To study the influence of impurities and to outline the precautions necessary in order to obtain from the crude material the highest possible grade of product.

Among other conclusions, Mr. Watts indicates that the raw material from the region studied has no superior for color, but that there is great need of some central depot at which the output of many small mines may be mixed and graded under the supervision of a trained ceramic chemist. Such control would insure the manufacturer receiving a product of known physical constants and would also insure a constant and ready market for the product. Mr. Watts has further called attention to the large quantities of first-quality kaolin now thrown away in mica mining; to the loss, in washing kaolin, of many tons of valuable flake mica that might be easily recovered; to ocher of excellent quality not now utilized; and to the fact that there is exposed on the dumps and worked-out dikes at least 200,000 tons of semikaolinized feldspar which, under proper technical control, might easily be utilized by potters.

The bureau's investigations have already progressed far enough to show that there can be no doubt of the United States being fully able to supply nearly all of the kaolin required for domestic consumption and that in quality the kaolin now available in the Appalachian region is excelled by none.

CHARLES L. PARSONS,
Chief, Division of Mineral Technology.

MINING AND TREATMENT OF FELDSPAR AND KAOLIN IN THE SOUTHERN APPALACHIAN REGION.

By A. S. Watts.

INTRODUCTION.

Throughout the Appalachian Mountains there are dikes of coarse granite or pegmatite, which were intruded into other rocks. These pegmatite dikes contain feldspar, quartz, white mica (muscovite), black mica (biotite), and other minerals, such as beryl, garnet, and tourmaline. The investigation here reported has to do only with the dikes of the southern Appalachian region, in which the abundance of each mineral is as in the order given above.

The pegmatites of this region are in every stage of alteration from those in which the feldspar is fresh to those in which the feldspar has decomposed to kaolin. The muscovite (white mica) shows no evidence of alteration, although most of the other associated minerals show traces of disintegration where the feldspar is completely kaolinized. At many places mining for mica has been done in dikes in which the feldspar is completely kaolinized, though the only evidences of disintegration in the mica are clay stains which are sometimes noted between the outside laminæ.

Mining in these pegmatite dikes antedates history, traces of prehistoric workings and some crude mining implements of stone having been unearthed by recent operations. The prehistoric mining is generally supposed to have been for mica, although investigations fail to show that the aborigines put the mica obtained to any particular use except for ornaments, a few mica ornaments having been found in mounds in this region.

The search for kaolin or semikaolinized feldspar is a plausible explanation of these prehistoric workings; all of them were in pegmatite that is more or less altered, and seemingly stopped only when the pegmatite became too hard to permit working with crude stone implements. The dumps do not represent the amount of material that one would expect, from their extent, the workings to have produced. The kaolin obtained was doubtless conveyed to the coast and sold to English traders for use in the manufacture of some of the early

English porcelains. Mention is made of this fact in various English records. An important fact bearing on this hypothesis is the recording, on December 6, 1744, of an application for an English patent for the production of porcelain from an earthy mixture produced by the Cherokee Nation in America. This was to be mixed with a frit formed by melting together sand and potash.[a] The earthy mixture was known as "unaker" by the Cherokee Indians, and doubtless derived its name from the Unaka Mountains which bound North Carolina on the northwest and in the foothills of which these pegmatite dikes occur in large numbers. The reference to this material as a mixture precludes the possibility of its being a pure kaolin, as pure white clay was known to the English prior to 1744; it was probably a mixture of kaolin, feldspar, and quartz, which are the products of all these altered dikes.

Modern working of these dikes for mica began in 1867 in Jackson and Haywood Counties, and a short time later the mines in Yancey and Mitchell Counties were opened. The modern working of these dikes for kaolin did not begin until about 1888, when kaolin mines near Webster, Jackson County, N. C., were opened.

In mining for mica in these dikes little or no attention has been given to the preservation or utilization of the associated materials, and likewise in mining for kaolin little or no attention has been given to saving the mica except where it occurs in large blocks. Mica mines throughout this district are surrounded by dumps of dike material, many of which contain thousands of tons. The kaolin in these dumps is practically valueless because it is so mixed with wall rock that its separation is impossible. Where the dike material is unaltered, it is in most cases broken into small fragments and so mixed with associated wall rock that only by tedious hand sorting can the feldspar be separated.

Early mining in these dikes was practically all of the "gopher" or "ground-hog" type, a low, narrow tunnel being driven in the mica-bearing band in the pegmatite dike. Where the mica is abundant the tunnel is widened and a room is cut out to enable the miners to remove all the mica at hand. When the pocket is worked out the narrow tunnel is continued along the strike of the dike. The miner brings to the surface only as much of the dike material as is necessary in order to leave a passage through which he may crawl. Once a room is worked out it is immediately packed full of the dike material removed in continuing the tunnel, and the wall rock or any pocket of stained kaolin encountered is thus mixed with what is otherwise valuable material and the whole is rendered worthless. If the mine is in unaltered pegmatite the miners generally fill these rooms with a mixture of material from the walls and the dike. To reopen these mines and recover the material filling these rooms, and to sort the material thus obtained, would doubtless prove a more expensive operation than to mine the material from undisturbed deposits.

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[a] Burton, Porcelain; its nature, art, and manufacture, p. 233.

Even to-day in recently operated mica mines in this district no care is being taken of the dike material and much valuable kaolin and feldspar is being lost.

If the dike material is properly sorted when mined, the cost of operating is only slightly increased and the full value of the material can be realized.

Lack of a market is given as a reason for the neglect of the dike material. The importance of commercial kaolin-washing plants and feldspar-grinding plants is thus evident.

With a cost of from $2 to $3 per ton for washing kaolin and a selling price of $9 to $10 per ton, it seems plausible that in the districts where mica is mined a price could be paid for crude kaolin, based on the actual kaolin content, that would encourage the mica miner to remove the kaolinized dike material with care and to deliver it later to the washing plant.

The same is true of many of the mica mines in unaltered pegmatite. The cost for crushing and pulverizing feldspar should not exceed $3 per ton, and with the ground potash-feldspar and mixed feldspars selling at $8 to $12 per ton a miner should receive enough for crude feldspar to pay a large proportion of the cost of mining. He probably could pay the cost of operating the mine from sales of crude feldspar or kaolin, so that the mica would be obtained without cost and hence be pure profit. Thus mica mining could be made a safe instead of an uncertain and unsatisfactory business. Even though the feldspar is albite (soda feldspar) it should have a value of $5 to $8 per ton when ground.

Some pegmatite dikes are of such low feldspar content as to be valueless or are so located that the cost of hauling is prohibitive, but these are the exceptions rather than the rule.

With the establishment of pottery and kindred ceramic industries in the South the dike products will become more easily marketable and their use will make possible a grade of ware not approachable by the use of even the finest foreign materials.

AREA INVESTIGATED.

The extent of the area investigated is shown approximately by Plate I.

Starting at Rome, Floyd County, Ga., and Dallas, Paulding County, Ga., as the southwest extremes, the belt of dikes producing feldspar, kaolin, and quartz follows a general northeast direction, but does not become of commercial importance until the northeast slopes of the Nantahala Mountains are reached. The dike belt here broadens and covers the territory from Clayton, Rabun County, Ga., to Bryson, Swain County, N. C. Here the first kaolin mining in the belt was done. The belt narrows gradually until it reaches Waynesville, Haywood County, N. C. Northeast of this point there are few dikes until Burnsville, Yancey County, N. C., is reached. Here the belt widens to about 20 miles and includes the Sprucepine (Pl. II), Penland, and Bakersville districts where operations are now extensive. Northeast of this district the dikes are less altered, only one dike of kaolin of any value being found until the Virginia line is crossed. Beyond this line the dikes are scarce and of little value until Bedford County, Va., is reached, where several important dikes produce both kaolin and feldspar. The investigation ended at Lynchburg, Va.

THE COWEE DISTRICT.

The Cowee district (Pl. III) lies northeast of the Nantahala Mountains and covers Macon, Jackson, and Swain Counties and a small part of Haywood County, N. C. The dikes here are very numerous and most of them are in an advanced state of kaolinization. In Macon County sixteen separate samples of kaolin, three samples of semikaolinized feldspar, and five feldspar samples were taken. In Jackson County eleven kaolin samples, three semikaolinized-feldspar samples, and three feldspar samples were taken. In Swain County six kaolin samples and one semikaolinized-feldspar sample were taken. In Haywood County five kaolin samples were taken.

THE MOUNT MITCHELL DISTRICT.

The Mount Mitchell district includes Yancey, Mitchell, and Avery Counties. Here the dikes are in all stages of kaolinization. In Yancey County five kaolin samples and two feldspar samples were taken. In Mitchell County eleven kaolin samples, two semikaolinized-feldspar samples and eight feldspar samples were taken. In Avery County two kaolin samples and three feldspar samples were taken.

Other mines or prospects outside these centers were studied, but most of them may be considered unimportant, although a few of the isolated dikes might be operated to advantage.

PEGMATITE DIKES.

OCCURRENCE.

The materials investigated are associated with or form a part of a coarse granite, or pegmatite, which occurs throughout the Appalachian Mountains.

A discussion of the origin and geologic occurrence of the dikes does not properly belong in this treatise. However, geologists agree that within the area covered by this investigation the pegmatites exist as dikes intruded into other rocks, probably in the fluid state, and, because the intrusion naturally occurred along the planes most easily fractured, the dikes lack uniformity in both direction and size.[a] They are lens-shaped, often pinching out within a few yards from a mass many yards wide to one only a few inches wide. The same is true of the perpendicular dimensions, although not to so pronounced a degree.

The majority of the dikes studied have high dips, 65 to 80 degrees. The general direction of the dikes is northeast, but many of the large dikes appear to strike due north or due east.

The entire area covered by this investigation is rough and mountainous, the level areas being confined to narrow river valleys and a few small plateaus. Most of the dikes now worked are well up on the mountain sides and some workable dikes have been found in the crests of mountains. Similar dikes are found, however, as low as the level of the river beds and are apparently no more advanced in kaolinization than are those at higher levels.

Every dike studied is intruded into a micaceous gneiss. This gneiss seems to have withstood weathering about as well as the intruded material, the wall rock being disintegrated about the same degree as the dike where kaolinization has occurred.

CONSTITUENTS.

The pegmatite of these dikes consists of feldspar and quartz in more or less intimate mixture, the rock varying in texture from fine-grained granite to intermingled masses of pure feldspar and pure quartz. In no case, however, has either mineral been found alone and the ratio of quartz to feldspar seems reasonably constant. Associated with the quartz and feldspar are mica (both muscovite and biotite), garnet, beryl, tourmaline, and small quantities of other minerals.

STRUCTURE.

The structure of some dikes is peculiar and leads one to believe that they may represent a series of intrusions.

Because of their irregular structure and the indistinctness of the walls, some very wide dikes can hardly be recognized as such. Such rock masses are undoubtedly great lenses formed at favorable positions along the strike of a dike. A fact worth noting in connection with these great lenses is that they are uniformly lower in feldspar and kaolin than are the better-defined and narrower dikes. A typical expanded-lens formation is shown in *A*, Plate IV. A section of a typical dike of the region studied is shown in figure 1, and a view of a dike in *B*, Plate IV.

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[a] Bastin, E. S., Feldspar deposits of the United States: U. S. Geol. Surv. Bull. 420, 1910, p. 10.

The material adjoining the hanging wall is nearly always quartz in a distinct band which may be a few inches or several feet thick. Next this quartz there is generally either a feldspar-rich pegmatite or a narrow band of feldspar-lean pegmatite carrying garnet, tourmaline, and other minerals. Adjoining this pegmatite is found the massive feldspar if such a band occurs in the dike. Adjoining the massive feldspar, if such occurs, one may expect to find a narrow band of massive quartz, or isolated lenses of quartz. Adjoining this are two or more bands of pegmatite, each band being distinct in size of grain and in percentages of quartz content and impurity. Generally these are next the quartz band along the wall. The mica generally occurs between the last pegmatite band and the quartz band, although it is not uncommonly found between the feldspar and pegmatite along the hanging wall. In fact the mica is rarely found continuously between any two given bands, and although the general position of the mica-bearing band rarely changes from one wall to the other in any one dike, the irregularity of the band makes mica mining an uncertain business.

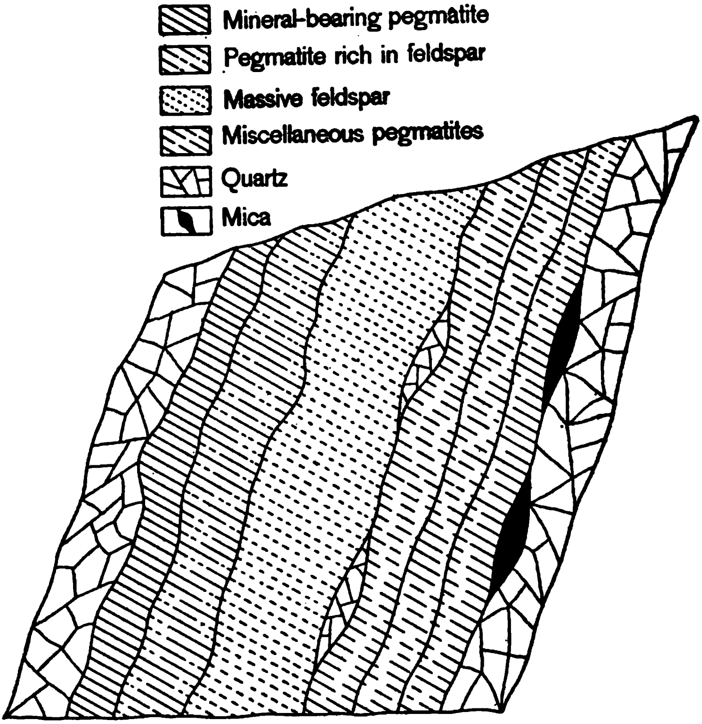
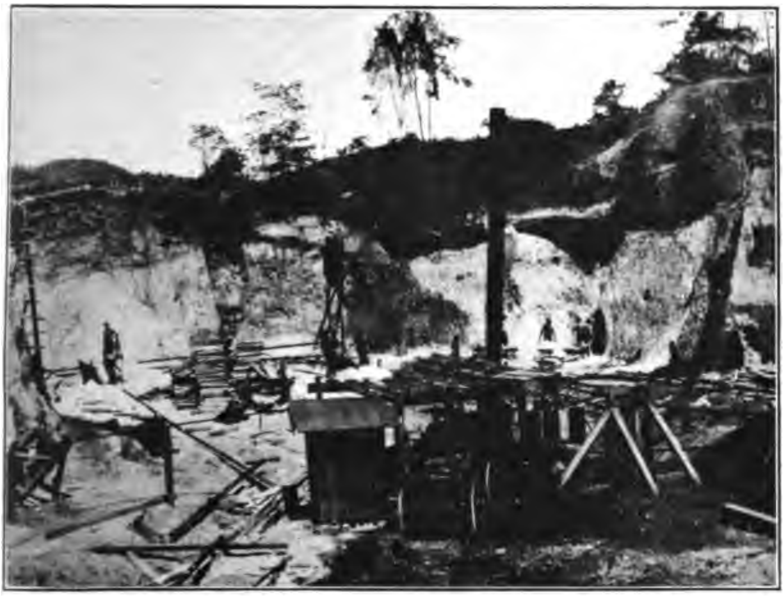


FIGURE 1.—Vertical section of a typical pegmatite dike.



A. TYPICAL EXPANDED-LENS FORMATION, SHOWING THE IRREGULAR SURFACE LINE OF THE KAOLIN.

B. KAOLINIZED DIKE, SHOWING TWO QUARTZ BANDS, ONE ADJOINING THE HANGING WALL ON THE RIGHT, THE OTHER NEAR THE CENTER.

Oxide of iron occurs as a stain in infiltrated surface clay, and is often so securely set in the crevices of broken bands that no amount of washing will remove it. Fortunately it seldom penetrates more than a few yards. Where a dike has kaolinized to any extent there occur pockets of iron-stained sand and inclosed lenses of iron-bearing micaceous gneiss which is altered to the same extent as the pegmatite and must be removed with great care, as it is exceedingly friable and its finely divided iron oxide content has enormous coloring power.

Garnets are rarely found as the sole impurity in pegmatite. With them are generally associated mica, either muscovite or biotite or both, and often beryl and tourmaline. Garnets are rare in the feldspar-rich bands, but are more plentiful in bands that are made up of quartz and mica. Many dikes that are rather low in feldspar would present industrial possibilities were it not for the iron garnets and the fine biotite mica that they carry. Beryl, on the other hand, is found almost entirely in those bands high in feldspar and low in quartz. Tourmaline, like beryl, is most abundant in the feldspar-rich bands. Manganese and cobalt as earthy oxides, generally wad, are associated with most of the dikes studied.

The quartz band that adjoins the hanging wall or footwall in most of the dikes is broken, apparently from cooling strains, and in the crevices thus formed occur the deposits of wad referred to above. The wad is brown or black, either powdery material loosely filling the crevices or nodules adhering to the quartz. Only in two instances was this material found intermixed with feldspar or kaolin. At one point in Macon County, N. C., a few nodules of wad were found in the kaolin bed, and in the Isinglass Hill kaolin mine these nodules are common.

Cassiterite (oxide of tin) is found associated with a kaolinized pegmatite dike at Lincolnton, Lincoln County, N. C., but this dike and the Isinglass Hill mine lie outside the district directly under investigation, both being south of the Blue Ridge Mountains. However, their occurrence and structure are so similar to those of the dikes being studied that it seems permissible to mention them here.

With the exception of the cassiterite and the wad in nodular form disseminated throughout the dike, the minerals mentioned above are common to every pegmatite dike studied and the problem of their removal or utilization confronts every present or prospective operator.

KAOLINIZATION.

The term kaolinization is used to signify the process of decomposition of feldspars and the recombination of some of the decomposition products to form kaolin. The process is as follows:

Kaolinization.

	By molecules.				By weight.			
Feldspar..........	1 K_2O	1 Al_2O_3	6 SiO_2		17 K_2O	18.4 Al_2O_3	64.6 SiO_2	
Loss by H_2O solution............	1 K_2O	....	....		17 K_2O	....	....	
Insoluble decomposition products	....	1 Al_2O_3	6 SiO_2		....	18.4 Al_2O_3	64.6 SiO_2	
Kaolin..........	....	1 Al_2O_3	2 SiO_2	[a] 2 H_2O	....	18.4 Al_2O_3	21.5 SiO_2	[a]6.44 H_2O
Free silica.........	....	....	4 SiO_2		....	....	43.1 SiO_2	

[a] Water of combination.

We thus see that of 100 parts of potash feldspar decomposed, 17 parts of potash are lost by solution and 43 parts of silica and 46.44 parts of kaolin remain; the kaolin is made up of 40 parts obtained from the feldspar (18.4 of alumina, and 21.6 of silica) plus 6.44 parts water of combination absorbed. The total of the insoluble products (plus the water of combination) is 89.44 per cent of the feldspar decomposed. A bed of residual kaolin (kaolinized feldspar) should therefore contain (minus the potash and plus the water of combination in the kaolin formed) 51.92 per cent kaolin and 48.08 per cent free silica.

This is on the assumption that the deposit is pure feldspar, but such an assumption is rarely true. In the area investigated the feldspars of the pegmatites are mixed with varying amounts of quartz. Other minerals are also present in small quantities, so that to find a kaolinized dike averaging 40 per cent pure kaolin is exceptional.

It rarely happens that the kaolin and quartz products of the feldspar disintegration are evenly distributed throughout the residual deposit. The tendency seems to be for the kaolin to filter down through the quartz particles until it has formed a compact mass where it packs together into a bed that may run 92 to 93 per cent kaolin. Below this bed in the decomposed dike lies another stratum of quartz sand which with depth becomes progressively richer in kaolin until another bed of nearly pure kaolin is encountered.

The extent of this process of disintegration and concentration varies in different dikes and in different localities, but the process is more or less evident in every dike studied.

As the extent to which kaolinization by weathering has progressed in the dikes examined varies inversely with the depth, it is not surprising to note that the plasticity of the kaolin decreases with the depth of a dike until the proportion of semikaolinized material becomes so great that deeper mining for kaolin is unpractical. This semikaolinized material, if devoid of plasticity, acts like feldspar or quartz sand in the washing process and may all be removed by the mica troughs and screens.

The depth at which this nonplastic material becomes noticeable in the dikes studied can be roughly set down at 40 to 45 feet, although the richest and apparently most plastic kaolin is always found when the present water level is reached. It is doubtful if this kaolin is really more plastic than the rich pockets met at higher levels, but it appears so owing to the excess of water that it carries. In some dikes the kaolin content of a decomposed dike steadily increases until water level is reached, and in such cases the deposit at that point is very rich.

The feldspar in the dikes is in all stages of decomposition, from fresh feldspar to perfect kaolin. The present topographic location seems to be no guide in determining the extent to which the kaolinization of a dike has progressed. Fresh feldspar and completely kaolinized feldspar lie almost side by side and at the same elevation. On Tremont Mountain, Macon County, N. C., fresh feldspar and kaolin deposits are only a few hundred feet apart at the same level. The two dikes are identical in structure, each having a vertical horse of pure quartz in the center, and narrow veins of mica-bearing pegmatite along the hanging and foot walls. At Penland, Mitchell County, N. C., a dike in an advanced state of kaolinization is being worked for kaolin, and 50 yards distant a dike containing fresh feldspar is being worked. In this case, however, the kaolin deposit is not well defined and appears to have been disturbed by a slide, whereas the fresh feldspar is in a well-defined dike. Near Jasper, Pickens County, Ga., a kaolinized dike follows the crest of a low ridge, while 100 yards distant and 50 feet lower is a dike with fresh feldspar.

Many other similarly associated dikes of feldspar and kaolin are mentioned in the description of the mines and prospects investigated.

PROSPECTING AND SAMPLING.

PROSPECTING FOR FELDSPAR AND QUARTZ.

Prospecting for feldspar and quartz is necessarily done either by open cuts or tunnels. The country rock is generally no more disintegrated than the pegmatite, so that the auger is useless. Wherever the pegmatite is rich enough in feldspar to justify mining, there are likely to be outcropping bands of quartz in place by which the presence and the direction of the dike are indicated. The first task, therefore, if the overburden is light, is to dig a trench exposing the full width of the dike.

The iron stains caused by infiltration from the overburden may extend several feet into the deposit and necessitate the removal of a considerable amount of the surface of the dike before satisfactory samples can be taken.

In determining the extent of the dike it is necessary to run cuts across the strike at intervals. The surface of the dike should be removed at least until fresh feldspar is exposed and each of the various bands should be measured and sampled across its entire face.

If these cuts are made at 50-foot intervals and the various bands occur in the same order and are approximately the same size there is little need of testing at shorter intervals, but if any irregularity occurs it is wise to reduce the distances between trenches to not more than 25 feet.

The trenches can in most cases be cut by plow and the material removed by scraper, although some hand labor is always necessary.

Where the overburden is so heavy as to render its removal impractical, the driving of a "tunnel" adit or crosscut may be necessary. This work is not different from that of driving any rock-tunnel of the same size, although the tunnel should be driven as far as practical from the heavy flint band which is badly ruptured in order to eliminate the danger from working in broken ground. By clearing the face a cross section of the dike can be obtained and by running a 25 or 50 foot tunnel and then crosscutting, a second face on the same cross section can be exposed.

It is also advisable wherever possible to crosscut the dike at two or more levels in order to ascertain whether the structure varies with depth. Care should be exercised in driving tunnels that enough slope is allowed for proper drainage and that sufficient headroom is provided for convenient operation. The quartz bands running with the feldspar may be prospected in the manner just described and in most cases the two can be conveniently worked together, the quartz being reached by crosscuts from the main entry.

SAMPLING OF FELDSPAR AND QUARTZ.

The full face of the dike should be exposed and each band measured. The sample can be most satisfactorily obtained by using a sampling cloth of generous size and, with a geologist's edged hammer, or a chisel and hammer, making a cut of uniform depth and width across the entire face. As is suggested in connection with the sampling of kaolin, the various bands should be sampled separately so that any undesirable material may be eliminated. For average samples of the entire deposit one has only to refer to the record of width of the various bands and to blend the separate samples proportionately.

For chemical and physical tests it is necessary to reduce a portion of the samples to a fine powder. The sample taken should be reduced to one-half inch size, spread evenly on a smooth sampling cloth or a large smooth paper, thoroughly mixed, and then quartered; if necessary the quarter taken may be crushed to one-eighth-inch size, thoroughly mixed and requartered, the mixing and quartering being repeated until a sample of suitable size for fine pulverizing is obtained. This sample should be pulverized in a hard porcelain or agate mortar until all of it passes a 120-mesh sieve.

PROSPECTING FOR KAOLIN.

Within the area studied very little prospecting has been done except the "ground-hog" mica mining, and this has resulted from exposure of mica-bearing ledges on the surface.

Dikes are so irregular that only by the most thorough prospecting can the extent of a deposit be ascertained.

The surface indications are mainly confined to scattered quartz bowlders except where a gulley exposes kaolin or pegmatite in place. A typical example of a bowlder-strewn surface is shown in *A*, Plate V. The white quartz bowlders, which were once a band of the dike, have alone withstood disintegration and are scattered over the surface.

Where such indications are found the prospector should bore with a standard wood auger welded to sectional steel pipe. If he finds kaolin, the boring should extend at least 30 feet into it. As a resistant flint band may be encountered at any time owing to nearly all dikes not being vertical, testing with the auger is often very unsatisfactory. The auger holes should be sunk at intervals of not more than 10 feet until the general direction of the dike is definitely determined and, if possible, its width and extent are ascertained. A great number of holes are certain to be sunk that can not be completed owing to auger striking hard quartz rock or penetrating loose sand. It is practically impossible even by putting water into the hole to remove the borings from a sand bed.

When the presence of a considerable deposit has been established, it will be found much more satisfactory and also more economical to open a tunnel or sink a shaft into the deposit than to investigate further by boring. Unless the deposit is to be worked at once, shaft sinking is not recommended except where the deposit is a great distance from the face of the hill. A tunnel can be cut quickly and easily at 25 to 35 feet below the top of the deposit and if it has a very slight grade it will drain the deposit down to that level. Samples should be carefully taken completely across the dike by means of a crosscut to one side of the deposit and by horizontal borings opposite this crosscut. By frequent horizontal borings the exact width of the dike may be ascertained, and the grade of material in the different vertical bands be determined. By a little overhead stoping to make room for handling the auger, borings in the floor of the tunnel can be made to any desired depth.

A prospecting tunnel should be not less than 6 feet high with an arched roof, but need not be more than 3 feet wide. If a flint horse is encountered it may be easily broken through or may be followed on either side, as it invariably runs parallel to the dike although its face is often more or less irregular.

Such a tunnel, if properly cut, will not cave for many years; several of the tunnels examined are still open and in good condition though driven 20 years ago and not repaired since.

The objections to shafts are the tendency to cave and to fill with débris, and the staining of the walls by surface waters. Furthermore, a shaft becomes a collecting point for subsurface water, the walls become soft, and it is practically impossible to do any sampling unless the water is removed by buckets, which is very expensive.

In the region examined auger holes soon become choked, and it is often more economical to bore a new hole than to reopen an old one; hence boring does not provide any means of permanently opening kaolin deposits for testing.

It must be borne in mind that the dimensions of the bands in a face are no criterion of what may be expected even a few yards beyond, hence the extent of the bands throughout the area tested alone can be considered in any prospecting report. This statement applies to horizontal rather than vertical dimensions although the latter are also subject to variation, especially those of the kaolin.

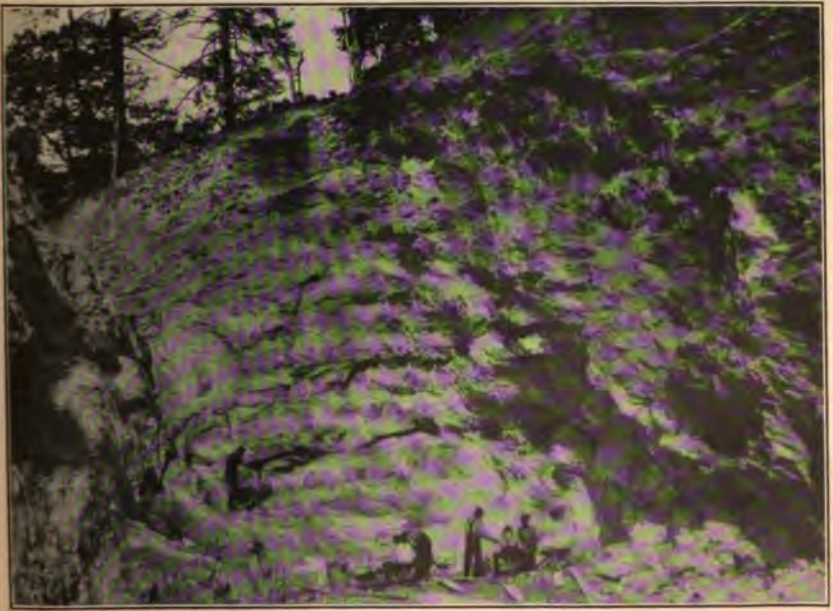
SAMPLING THE KAOLIN DEPOSIT.

The method of taking the samples for test is of the utmost importance. Even after the deposit has been carefully proved throughout its length and depth, a lack of care in sampling may render the data obtained of little value.

When samples are taken by boring from the surface the author has found it advisable to use a larger bit for boring through the overburden. To prevent any particles of overburden falling in, the sides of the hole should be well packed with a smooth round pole or sapling before boring into the deposit begins.

A careful record should be made of the appearance of each sample as it is removed from the auger and in case a sample looks notably different it should be kept separate. Not over 5 feet of borings should be sampled into one bag, as the mixing of large samples may lead to wrong conclusions. In vertical sampling the sampler should remember that he usually cuts the deposit obliquely and may strike a narrow band of undesirable material that could be removed in mining. The borings from such a band because of its loose texture and the

A. TYPICAL SURFACE INDICATIONS OF A DISINTEGRATED PEGMATITE DIKE. THE WHITE BOULDERS ARE DERIVED FROM A QUARTZ BAND IN THE DIKE.



B. OPEN-CUT MINING FOR FELDSPAR.

tendency of the auger to tear off particles when raised and lowered may make the band seem thicker than it really is.

A careful record should be kept of all samples, the point at which taken and the depth being noted. The importance of taking complete notes should be constantly borne in mind.

In sampling a tunnel the problem of obtaining satisfactory samples is much simpler but the tendency to collect false samples is even greater than in sampling by bore holes from the surface.

Where a large area of material is exposed, the tendency is to go to that section which appears most promising and to take the samples there. The most satisfactory method of sampling a tunnel is to divide it into 5 or 10 foot sections and sample each separately. As the dike bands vary horizontally rather than vertically, it is always advisable to sample the crosscuts, and in sampling these, as in sampling auger holes, much care must be observed to prevent a narrow band of impure material from being given more importance than it deserves.

First, clean the face exposed in one side of the crosscut with a shovel. Then sample each band separately across its full width. If stained material is encountered, its approximate extent can be determined and a sample preserved for test. In some dikes the kaolin shows peculiar variations in tint that can not be detected after washing.

The preservation of these samples separately is very important, since, as will be shown, different portions of the deposit may possess different physical properties, thus rendering a blending advantageous. Also it is possible, if desired, to blend the different samples in the same proportions in which they exist in the deposit, and thus obtain a sample representative of the entire deposit.

TESTING THE SAMPLES.

FELDSPAR.

Feldspars may be divided into three classes, as follows:

Potash feldspars, including orthoclase and microcline. Their composition is $KAlSi_3O_8$, their specific gravity is 2.56.

Soda feldspar, known as albite. Its chemical composition is $NaAlSi_3O_8$, its specific gravity is 2.605.

Lime feldspar, known as anorthite. Its chemical composition is $CaAl_2Si_2O_8$, its specific gravity is 2.765.

In addition there are mixtures of these feldspars, as follows:

Potash-soda feldspar, known as anorthoclase, which is a mixture of equal parts of potash and soda feldspars.

Soda-lime feldspars, known as plagioclase feldspars, which vary in composition from a mixture of 6 parts soda feldspar and 1 part lime feldspar to 1 part soda feldspar and 6 parts lime feldspar.

If the feldspar is pure, its value in the industries is indicated in a very satisfactory manner by a chemical analysis. If, as is the case in nearly all pegmatites, the feldspar is intimately mixed with a number of other minerals in varying proportions, a chemical analysis is often decidedly misleading. If a quantity of feldspar is freed from associated minerals, an analysis can be obtained that will indicate which of the feldspars is present.

For the process of chemical analysis of feldspar, see United States Geological Survey Bulletin 422. If a mixture exists, a microscopic study of the sampled material shows conclusively what minerals are present and also their fineness and their relations; it is therefore a valuable aid in classification.

If the consumer knows what minerals are present and knows their average proportions, the task of readjusting his mixtures to suit conditions is not a serious one, provided the associated minerals do not introduce some undesirable colorant.

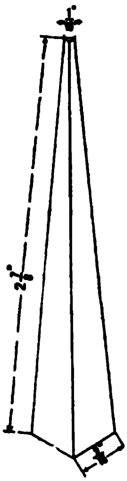


FIGURE 2.—Standard cone for deformation test.

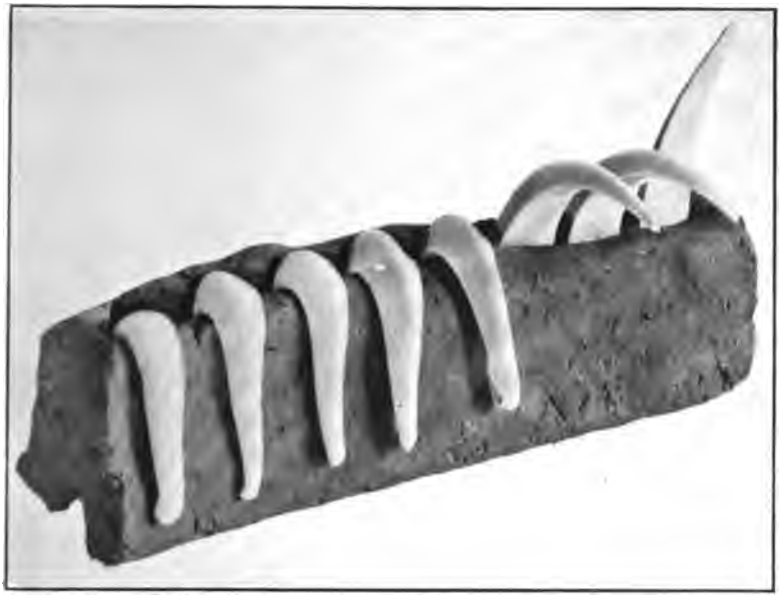
THE DEFORMATION POINT AND ITS DETERMINATION.

Since feldspars are fusible, their activity as solvents depends on temperature. The determination of the deformation point of a feldspar is a matter of importance.

The deformation point of a feldspar is determined as follows:

The feldspar is pulverized to an impalpable powder, as explained under "Sampling." This powder is mixed with just sufficient starch paste or dextrin solution to permit of its being formed by pressure into a cone. The size of the cone for temperatures up to 1,450° C. has been standardized (Seger cones are shown in *A*, Pl. VI) and in practice is a three-sided pyramid with sides 2⅞ inches long and the faces $\frac{9}{16}$ inch at the base and $\frac{1}{16}$ inch at the top, as shown in figure 2.

This cone is comparable with the standard pyrometric cones manufactured in Germany and in the United States, which are guaranteed to melt at definite temperatures under exact heating conditions. These cones, composed of mineral mixtures, act under fire in a manner more or less similar to the feldspars, kaolins, and quartzes, in the standardization and firing of which thev are chiefly used.



A. SEGER CONE.

B. HOUSEHOLD CHURN AS LABORATORY AGITATOR IN KAOLIN WASHING.

Seger cones and their deformation temperatures.

Cone No.	Deformation temperature.	Cone No.	Deformation temperature.	Cone No.	Deformation temperature.
	°*C.*		°*C.*		°*C.*
1	1,150	13	1,390	25	1,630
2	1,170	14	1,410	26	1,650
3	1,190	15	1,430	27	1,670
4	1,210	16	1,450	28	1,690
5	1,230	17	1,470	29	1,710
6	1,250	18	1,490	30	1,730
7	1,270	19	1,510	31	1,750
8	1,290	20	1,530	32	1,770
9	1,310	21	1,550	33	1,790
10	1,330	22	1,570	34	1,810
11	1,350	23	1,590	35	1,830
12	1,370	24	1,610	36	1,850

Cones similar to the Seger cones are made for temperatures below 1,150° C., but for testing feldspars, kaolins, and quartzes such cones are unimportant.

For temperature determination, other forms of pyrometers are also used.

THERMOELECTRIC PYROMETER.

The thermoelectric pyrometer is an instrument for ascertaining the temperature in an oven or kiln. It consists of a thermoelectric couple, made by fusing a platinum wire and a wire composed of 90 per cent platinum and 10 per cent rhodium, which is exposed to the temperature. The difference in temperature between the hot and the cold junctions of these two wires is proportional to the electric current generated, and this is recorded on a galvanometer. The deflection of the galvanometer varies with the current generated, and the dial of the galvanometer, being scaled in centigrade degrees, permits the operator to read directly the temperature of the furnace. Such an instrument is reliable to 3° C. under ideal laboratory conditions and is reliable within 5 to 10 degrees under factory conditions. The electric pyrometer is highly satisfactory for use in testing feldspars, but as the deformation of a feldspar is a pyrochemical process, in which heat and time are factors, the time consumed in heating the sample to the deformation temperature should be considered in expressing the deformation temperature of any feldspar or feldspar mixture.

The thermoelectric pyrometer deteriorates rapidly at temperatures above 1,500° C.; hence for testing kaolins and quartzes Seger cones or some form of heat-radiation or optical pyrometer must be used.

HEAT-RADIATION PYROMETER.

In the heat-radiation pyrometer the heat radiated from an incandescent body, in the furnace or kiln, is focused upon a thermocouple and the electromotive force generated is indicated by the deflection of an attached galvanometer, which is read upon a dial scaled in centigrade degrees. The precautions that the operator must consider in operating such a pyrometer are to have the incandescent object focused sharply upon the thermojunction and to have the image so focused of greater size than the junction.

Such a pyrometer is reliable only within 10° C. under the most favorable conditions; hence its use is little, if any, more satisfactory for temperature measurements than are the pyrometric cones.

OPTICAL PYROMETERS.

The optical pyrometer of La Chatelier consists of a telescope that carries a small comparison lamp attached laterally. The image of the flame of this lamp is projected on a mirror at 45 degrees placed at the principal focus of the telescope. The images of the object viewed and of the comparison flame are side by side and are brought to equal intensity by suitable adjustment of the instrument. Under the most favorable conditions this instrument is subject to any error of vision of the operator and for high temperatures should hardly be expected to give results more accurate than 10° C.

As the deformation of feldspars may in some cases be completed within a temperature range of 5° to 8° C., the use of thermocouples or optical pyrometers does not furnish a graphic comparison. Seger cones placed side by side with the sample to be tested is by far the most satisfactory method of comparison, although it is always advisable to use a thermocouple or optical pyrometer to check the temperature of the deformation.[a]

The cone of material of which the deformation point is to be determined is placed on a fire-clay slab to which it is made fast by means of a fusible slip or by packing clay about the base. If clay is packed about the base care must be used that the cone be set not more than one-fourth inch in the clay lest the deformation be retarded. If the deformation temperature is to be determined by means of cones, these should be placed about the cone to be tested and as near as possible without danger of contact when deformation begins. If the cones are not set exactly vertical, care must be taken that the same slant be given to all, otherwise the results will not be comparable.

As the rate of fusion is an important factor, the cones should be closely watched and the time at which each standard cone is exposed to the heat should be recorded as well as the time at which its point reaches the level of its base, thus forming a semicircle. A similar record for the cone of the material being tested enables one to state, by referring to the standard-cone record, the temperature of the beginning of deformation and also the temperature at which its point reaches the level of its base. The range of temperature between these two stages of deformation is very important as indicating the range of temperature within which the material under test will be valuable as a flux in pottery manufacture.

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[a] For more complete explanation of Seger cones, see "Seger's Collected Writings" (Am. Trans.), vol. 1, pp. 224–229; also Prof. Paper 11, and Bull. 54, U. S. Geol. Surv.

For electrical, radiation, and optical pyrometers, see "High-Temperature Measurements," by La Chatelier, Boudouard, and Burgess.

Waidner, G. W., The temperature work of the Bureau of Standards: Jour. Ind. Eng. Chem., vol. 2, 1910, p. 49. Waidner, G. W., and Burgess, G. K., Platinum resistance thermometry: Bureau of Standards Scientific Paper 124, 1909, 82 pp.

Shook, —, Radiation pyrometry, I, Met. Chem. Eng., vol. 10, 1912, pp. 238, 334, and 534; Calibration of radiation pyrometers: Op. cit., p. 416; Determination of very high temperatures: Op. cit., p. 478.

Wilson, —, A practical note on thermo-electric pyrometers: Electrochem. Met. Ind., vol. 7, 1909, p. 116.

COLOR.

Feldspar, as found in nature, has various tints and shades, but the fused material, to possess much value, must be almost colorless. Until a feldspar has been heated past the deformation point and come into quiet fusion it generally remains opaque. The opacity may be due to bubbles disseminated through the mass, or to some opaque impurity not taken into solution by the feldspar. The presence of an impurity that discolors is far more objectionable than one that merely opacifies although for many uses a feldspar that is opaque after fusion is very objectionable.

No classification of colors and shades of feldspar has been attempted. For the standardization of the feldspars in the following investigation a high-grade Maine feldspar was accepted as standard color.

This standard Maine feldspar has the following composition:

Chemical analysis of standard Maine feldspar.

[Analysis by Ohio Geological Survey.]

SiO_2	71.75
Al_2O_3	16.70
Fe_2O_3	.14
TiO_2	.03
CaO	.25
MgO	
Loss on ignition	.35
K_2O	8.59
Na_2O	2.99
	100.80

This analysis indicates a mineral composition as follows:

Mineral composition of standard Maine feldspar.

Microcline	50.3
Albite	27.25
Kaolin	5.08
Free silica	17.37
	100.00

The high content of free silica and the kaolin content cause this feldspar to remain opaque to a much higher temperature than it would otherwise, but the low ferric-oxide content insures a fusion practically free from color.

To classify the feldspars, the fused specimens are placed side by side and by comparison with the standard feldspar and with one another a color scale is devised in which each specimen has its place. By repeating this several times the danger of error is reduced to the minimum and by having two or more persons duplicate tests, the personal error is largely eliminated. The errors possible from this system are many and the absence of any standards of color for such work is the only justification for its use.

THE IMPURITIES OF FELDSPAR.

QUARTZ.

The presence of quartz in feldspar offered for sale has long been considered unpermissible, even though the user expected to add quartz to the mixture later. This stand was taken because of the fear that the feldspar would be adulterated enough to reduce its solvent action seriously. The impression has also prevailed that even small additions of quartz to feldspar would greatly increase the amount of heat necessary to fuse the mass to a liquid state. As exact data on this subject were absolutely lacking, the author carried on an investigation with additions of pure quartz to a pure feldspar, an analysis of which follows:

Feldspar used in deformation study of feldspar-quartz mixtures.

Composition.		Theoretical microcline.
H_2O	0.17	
SiO_2	65.37	64.75
Al_2O_3	17.92	18.34
TiO_2	Trace.	
Fe_2O_3	.02	
CaO	.17	
MgO	Trace.	
K_2O	13.05	16.90
Na_2O	2.10	
	98.80	99.99
Specific gravity	2.57	2.56

These materials were ground separately to pass a 200-mesh screen. They were then ground together until thoroughly mixed and made into cones similar to the pyrometric cones of commerce against which they were to be tested. They were burned in an updraft testing kiln with a muffle 7 by 8 by 18 inches deep. Gas was the fuel, and an even temperature throughout could be maintained by slow and careful increase of gas pressure. The following is the record of the test burn:

Twenty hours was consumed in reaching cone 7 temperature, 1,270° C. Eight hours additional was consumed in raising the temperature to cone 9, 1,310° C.

With the rate of deformation of cone 8, 1,290° C., and cone 9, 1,310° C., as standards, figure 3 shows the relative temperatures and speed of deformation of the various mixtures of feldspar and quartz up to and including 35 per cent quartz.

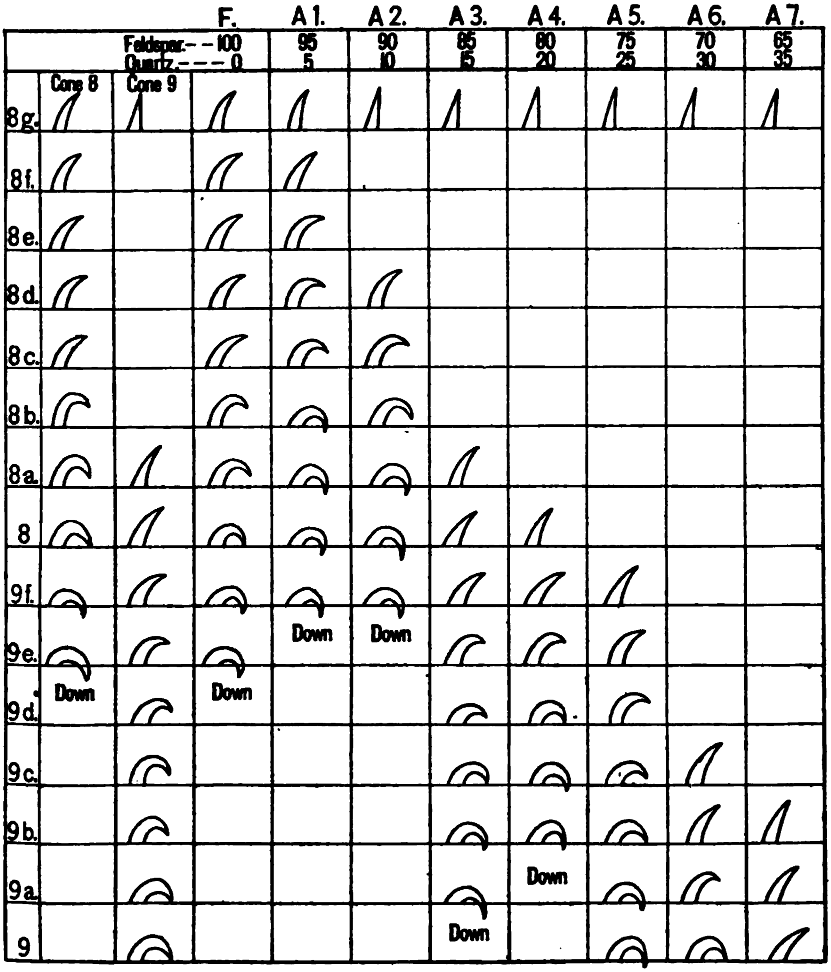

FIGURE 3.—Deformation of feldspar-quartz cones, showing relative temperatures and speeds.

Note that even though 30 per cent of the mixture is quartz, the deformation temperature is raised less than two cones, or 40° C. This is not in accordance with the work of Simonis,[a] who found that a mixture of 70 per cent feldspar and 30 per cent quartz had a deformation temperature of cone 14, 1,410° C., which is about 100° C. higher than his deformation point for pure feldspar.

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[a] Sprechsaal, 1907, pp. 403-406.

This difference in results can be accounted for only by the fact that the feldspar used in the Simonis's tests was pure potash feldspar, whereas the feldspar used in these tests carries more than 2 per cent Na_2O.

The important point brought out by this investigation is the fact that the user can not be certain that he is obtaining pure feldspar by testing the material alone in the kiln in the manner ordinarily practiced. A mixture of 95 per cent feldspar and 5 per cent quartz begins to deform at the same temperature as pure feldspar, but becomes fluid much more quickly than pure feldspar. A mixture of 90 per cent feldspar and 10 per cent quartz deforms at a temperature approximately 5° C. higher than does pure feldspar, but becomes liquid before the pure feldspar has begun to lose shape.

No eutectic indications are noticeable in the original fusion of feldspar-quartz mixtures, unless one so construes the fact that the mixture of 95 per cent feldspar and 5 per cent quartz began deforming when the feldspar began and completed deformation before the pure feldspar. To determine if there is any eutectic indication in feldspar-quartz fusions, mixtures of pure feldspar and quartz were fused together in the above proportions and after reducing the fusions to 200-mesh powders they were made into cones which were tested against standard pyrometric cones as before.

The same order of fusibility is noted in this firing as was recorded in the firing of the original mixtures. F and A1 begin to deform at cone 5, 1,230° C., but, as was noted in the firing of the mixtures, A1 deforms more rapidly and touches the plate when F is only half down. A2 begins to deform after F and A1 have started but overtakes F when nearing the plate. A3, A4, A5, A6 deform in regular order. A7 was an imperfect cone and no reliable observation of it could be made but A6 was deformed so that it touched the plate before cone 7 started to deform.

IRON OXIDE.

Iron oxide is so well known as a dangerous impurity in feldspar that a discussion of it seems almost unnecessary. Only 1 per cent gives the feldspar a decided yellow cast and it must be eliminated even though hand sorting is necessary.

MUSCOVITE.

As muscovite is present in nearly every feldspar-bearing dike in the district studied, it is important to know what influence it exerts on the deformation point and color of the feldspar. For this purpose a series of feldspar-muscovite mixtures was made and tested in the same manner as the feldspar-quartz mixtures. The muscovite and the feldspar were both ground to pass a 200-mesh sieve. Figure 4 shows the results of this test. The results are especially interesting in view of the fact that muscovite has the composition, $K_2O.3Al_2O_3.6SiO_2.2H_2O$, and contains the same elements as feldspar; but by virtue of its higher alumina content it is more difficultly fusible, being reported by Rieke[a] as deforming with cone 13.

In figure 4 it will be noted that C1, containing 5 per cent of muscovite, begins to deform before any other mixture tested. The order in which the various mixtures deform is regular, C4 being the last to begin to deform. The rate of deformation, however, appears to be just the reverse of this, since C4 deforms until it touches the plate before any other of the series. Note also that as C1, which has the slowest rate of deformation, touches the plate F, which is pure feldspar, shows the first indication of deformation. Thus it appears that additions of finely ground muscovite to a potash feldspar lower the deformation temperature, and the rate of deformation increases with the increase in muscovite.

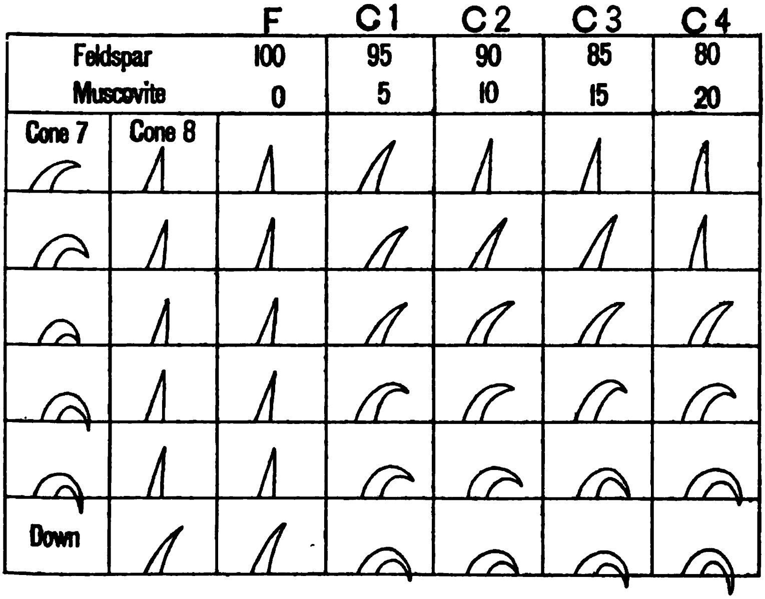

FIGURE 4.—Deformation of feldspar-muscovite cones, showing relative temperatures and speeds.

The influence of muscovite upon the color of the feldspar is really the most important consideration in the presence of muscovite, although the proportions present in any deposit known would hardly average 1 per cent. A specimen containing this percentage is scarcely distinguishable from pure feldspar. The tint produced by the muscovite is a pale drab, which is the same as is imparted to porcelains by the ball clay and hence would not be noticed.

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[a] Rieke, —, Sprechsaal, 1906, p. 578.

BERYL.

The presence of crystals of beryl in the pegmatite dikes and the fact that they are found chiefly associated with the portions richest in feldspar made it necessary to ascertain what effect this mineral exerts upon the industrial value of feldspar.

For this purpose a series of mixtures of microcline and beryl was prepared, ground to 200-mesh fineness, and made into cones. These cones were tested in the same manner as were the feldspar-quartz and feldspar-muscovite mixtures, and the results are shown in figure 5.

Beryl has the following composition: $3BeO.Al_2O_3.6SiO_2$.

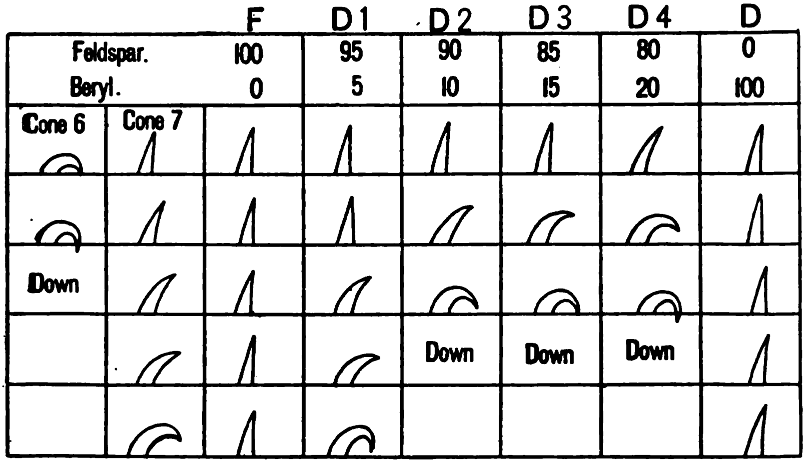

FIGURE 5.—Deformation of feldspar-beryl cover, showing relative temperatures and speeds.

The first of this series to deform is D4 which begins to deform as cone 6 touches the plate. The mixtures D3, D2, and D1 follow quickly after D4. The feldspar-beryl mixtures continue to deform in the order in which they start, the first to begin deforming being the first to touch the plate. The entire series deforms completely within less time than one cone temperature range, starting at cone 6, touching and extending to cone 7, not quite touching the plate. This series indicates that the deformation temperature decreases with increase of beryl content, at least to 20 per cent where the series ended. As a test cone of pure beryl was tested with this series and was heated to the temperature of cone 8 without deforming, a eutectic is indicated between feldspar and beryl. A study of the fired cones indicates slightly more deformation in the D3 mixture, but as this was not apparent during deformation its significance is difficult to determine.

BIOTITE.

In the dikes investigated, the biotite is generally finely divided and rarely occurs in pegmatite rich in feldspar. Where present in such quantity as to make the sorting and cobbing of the entire deposit necessary it is doubtful if the expense of such work would be justified. Where present as isolated laths or crystals, such portions of the deposit may be rejected and the remainder made marketable. The presence of biotite in any quantity renders the feldspar unmarketable except as low-grade. The injurious constituent of biotite is iron, the content of which varies greatly.

GARNET.

The influence of andradite (calcium-iron garnet; composition, $3CaO.Fe_2O_3.3SiO_2$) on the deformation point and color of feldspar was investigated. Brush and Penfield[a] report the fusibility of this mineral as lower than orthoclase. The results of the investigation indicate that a mixture of 5 per cent andradite and 95 per cent feldspar deforms at a temperature at least one cone lower than does pure feldspar. This percentage of andradite imparts to the fused feldspar a seal-brown color that does not show any diminution in intensity at higher temperatures. When 1 per cent andradite is used the color imparted is pale brown or green, depending on kiln conditions during the test.

TOURMALINE.

An investigation of the influence of tourmaline on the deformation point and color of feldspar was made. The mineral has a very complex and variable composition: $R_9Al_3BOHSi_4O_{19}$. It fuses usually at a much lower temperature than feldspar, although its composition may make it as refractory as orthoclase. The tourmaline found in the dikes studied must contain an appreciable amount of iron since a mixture of this 5 per cent tourmaline and 95 per cent feldspar produces a strong golden-brown glass at cone 10, and deforms at the same temperature as feldspar.

MANGANESE AND COBALT OXIDES.

An investigation of the influence of manganese and cobalt in the form of wad on the deformation point and color of feldspar was next made. At low temperatures a mixture containing 5 per cent of the wad has a color varying from brown to deep wine, but as the temperature increases the color fades because of the volatilization of manganese dioxide until at cone 10 only a pale lavender tint remains.

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[a] Brush, G. J., Determinative Mineralogy, revised by S. L. Penfield, p. 269.

SUMMARY.

From the foregoing it is apparent that neither muscovite or beryl need be feared as impurities in feldspar, in regard to either, their color or effect on the temperature of deformation.

The presence of iron garnets in feldspars must be carefully avoided because even when present in very small amounts they ruin the color of the fused feldspar.

Tourmaline ranks next to iron garnets as an injurious impurity in the dikes investigated, and while not so powerful a colorant as iron garnets, it should be carefully avoided on account of the undesirable color which it imparts.

Wad imparts an intense purple-brown color at temperatures below cone 8, but at this temperature the color is reduced to a faint amethyst hue, hence its presence is not so serious, as the color imparted tends to neutralize the yellow color of iron, especially if cobalt is present with the manganese.

PROPERTIES OF FELDSPAR IN PORCELAIN MIXTURES.

The rôle of feldspar in the porcelain mixture is that of a cementing material or solvent, its activity depending upon the temperature attained in the firing process. If the temperature only softens the feldspar the latter can do nothing more than bond the quartz and kaolin with which it is intimately mixed. If the feldspar is heated until it becomes fluid, it can take into solution part of the quartz and kaolin, and thus form a more or less homogeneous mass. Impurities in the feldspar may not appear greatly injurious in their action when the feldspar is tested alone, but may materially affect the speed of reaction and other properties of the feldspar when used in porcelain mixtures.

The action of a feldspar in porcelain mixtures is the only safe and proper basis for judging its industrial value. Experience has proved that it is not essential that the proportions of a porcelain mixture for testing be industrially correct but rather that those proportions be selected which will cause the ingredients to display most pronouncedly any faults that they possess. Thus an excess of feldspar will increase the tendency to warp and also to produce bad colors. For practical test, the following proportions have been found most satisfactory: Feldspar, 20 per cent; kaolin, 50 per cent; and quartz, 30 per cent, mixed with 50 grams of water.

A standard for each of these materials should be selected from the best material on the market and should be thoroughly tested as to its physical and chemical properties. From these standard materials a standard trial or blank should be prepared in the proportions given above and this standard trial should be tested in exactly the same manner as the mixture containing the material under test.

STANDARD PLASTIC TRIALS.

The standard plastic trials are produced by mixing the materials in the proportions given above. Especial attention should be given to the thorough mixing of these materials into a homogeneous mass, as otherwise the trial lacks uniformity and is unreliable. After being thoroughly mixed and kneaded the material is formed by jiggering or by pressing into molds in such a manner that a product of varying thickness will be obtained.

For this trial a wedge-shaped rectangular block, which may be any desired length, is most satisfactory. If one edge is sharp and the other three-fourths inch thick the trial can be used for translucency and color tests; and by impressing the face with a metal die a record of linear shrinkage may also be obtained. Care should be observed that this mark for shrinkage or identification does not interfere with the translucency test.

For testing the feldspar a mixture should be prepared in every way similar to the standard trial or blank, except that the feldspar to be tested should be substituted for the standard feldspar. In the molding of trials the process employed in producing the standard trials must be carefully duplicated if comparable data are expected. All test pieces should be conspicuously marked to insure identification.

As soon as trials are removed from the molds they should be placed where they may dry without warping, and when thoroughly dry the drying shrinkage may be determined by measuring with calipers the impression made by the die.

FIRING.

The firing of the trials now takes place. The temperature attained should be that to which the feldspar will probably be subjected in commercial work. For convenience this temperature may be safely assumed as about that at which in the deformation of the trial the point reaches the level of the base, as described under deformation-point determination.

VITRIFICATION RANGE.

Vitrification range is that range of temperature within which the feldspar being tested produces a vitreous body that does not warp. The vitrification range of feldspar is determined by means of a bar ½ by ½ by 6 inches composed of a mixture similar to the standard porcelain mixture, except that the standard feldspar is replaced by the feldspar being tested.

This bar, after thorough drying, is so placed in the kiln that it is supported 1 inch from each end, leaving the 4 inches in the middle unsupported. The temperature at which warping begins marks the highest temperature that is practical for this feldspar in this proportion and is considered the maximum temperature of the vitrification range. The minimum temperature of the vitrification range is determined by firing to various temperatures the trials containing the feldspar being tested; they are then carefully weighed dry, and after standing for 24 hours in pure water are removed, carefully dried on the surface only, and reweighed. The increase in weight indicates the absorbed water. The minimum temperature which renders the trial nonabsorbent is the minimum temperature of the vitrification range.

COLOR.

In the absence of a standard system of measuring color, the method employed is by comparison, using the standard porcelain mixture made and fired under comparable conditions as a standard.

TRANSLUCENCY.

Translucency is determined by placing the wedge-shaped translucency trials over a 1-inch hole in a box that contains a 16-candle-power electric lamp of constant brilliancy. The maximum thickness of the trial, expressed in centimeters, through which a No. 20 wire can be detected on the face of the trial next the lamp, with the lamp 3 inches distant, is taken as the measure of translucency.[a]

SHRINKAGE.

Shrinkage is determined by measuring the length of the die impression made in the translucency wedge. The total shrinkage is the difference between the original length and the length after firing.

TEST UNDER GLAZE.

An important property of all feldspars is their influence upon the color of the body, both unglazed and glazed. Many porcelain bodies are of faultless color when unglazed, but when covered with a clear glaze the defects of the ingredients appear and the body as viewed through the glaze is so badly off-color that the commercial value of the ware is greatly reduced. Tests under glaze are therefore of much importance, and since the glazes used are of two classes—namely, raw-lead and fritted—it is advisable whenever possible to apply to the once-fired trials a thin coat of glaze. For convenience it is desirable to place a small quantity of each glaze upon the same trial or test piece in order that the effects of the different glazes may be most clearly compared. A small portion of the trial should be left unglazed in order that the effect that glazing has on the color may be determined by comparison.

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[a] See Trans. Am. Ceram. Soc., vol. 13, 1911, pp. 104–105.

For tests of materials in porcelain mixtures under glazes, those glazes should be chosen that are most likely to be used with the materials in commercial work.

For this test the following glazes are found satisfactory and are recommended for use at temperatures between cone 02 and cone 2—that is, approximately, 1,110° to 1,190° C.

Raw-lead glaze.

Molecular formula.

$$\left.\begin{array}{l} 0.6\ PbO \\ 0.1\ K_2O \\ 0.15\ CaO \\ 0.15\ ZnO \end{array}\right\} 0.15\ Al_2O_3\ .1.5\ SiO_2$$

Composition of batch by weight.

White lead	51.81
Potash feldspar	18.60
Whiting	5.02
Zinc oxide	4.20
Kaolin	4.32
Flint	16.05
	100.00

This material is ground with water enough to produce a thin paste and is applied as a coat of uniform thickness to all the test pieces to be compared.

Fritted glaze.

Molecular formula.

$$\left.\begin{array}{l} 0.13\ K_2O \\ 0.25\ Na_2O \\ 0.25\ ZnO \\ 0.25\ CaO \\ 0.12\ PbO \end{array}\right\} 0.22\ Al_2O_3 \left\{\begin{array}{l} 1.25\ SiO_2 \\ .50\ B_2O_3 \end{array}\right.$$

Composition of batch by weight.

Melted frit	37.02
Potash feldspar	31.02
White lead	13.30
Zinc oxide	8.70
Kaolin	9.96
	100.00

Frit.

Molecular formula.

$$\left.\begin{array}{l} 0.5\ Na_2O \\ 0.5\ CaO \end{array}\right\} \quad \left\{\begin{array}{l} 0.58\ SiO_2 \\ 1.00\ B_2O_3 \end{array}\right.$$

Composition by weight, raw.

Borax	69.25
Whiting	18.13
Flint	12.62
	100.00

This frit is melted to a glass and then ground to pass a 150-mesh sieve. The ground melted frit is added to the glaze in the proportion given above, and the mixture is thoroughly ground before being applied to the trials. The fritted glaze is generally applied in a thinner coat than is necessary for the raw-lead glaze.

BLANK OR STANDARD TRIAL FOR FELDSPAR.

The blank or standard trial for feldspar consists of the standard porcelain mixture, and contains the standard feldspar, kaolin, and quartz in the proportions specified.

The standard feldspar has a chemical composition as follows:

Composition of standard feldspar.

H_2O	0.35
SiO_2	71.75
Al_2O_3	16.70
Fe_2O_3	.14
TiO_2	.03
CaO	.25
MgO	....
K_2O	8.59
Na_2O	2.99
	100.80

The standard feldspar has a deformation temperature range of 1,300° to 1,320° C. When fused, it becomes a milky glass without any yellow tint.

PROPERTIES IN STANDARD PORCELAIN MIXTURE.

In the standard porcelain mixture this feldspar produces a vitreous mass at 1,310° C. and at 1,350° C. shows no indications of warping.

The color is a vitreous white without any distinguishable cream or blue tint.

At 1,350° C. the feldspar produces a translucency of 0.65, and a total shrinkage of 15.6 per cent, 3 per cent of which is drying shrinkage and 12.6 per cent firing shrinkage.

KAOLINS.

Kaolin, or white-burning residual clay, varies more or less in its physical and chemical properties, depending on the rock of which it was a disintegration product. When freed from the other residual material with which it is almost invariably mixed, its chemical composition approaches very closely that of the mineral kaolinite.

Kaolinite has the formula $Al_2O_3.2SiO_2.2H_2O$, which, expressed in percentages, is as follows:

Composition of kaolinite.

SiO_2	46.3
Al_2O_3	39.8
H_2O	13.9
	100.0

Specific gravity, 2.6.

An ultimate chemical analysis, by which the percentage of each component of the kaolin is determined, is valuable as indicating the impurities present and the proportions in which the various components are present, but without additional data in regard to the physical properties and the mineral composition of the kaolin one can form little idea from such an analysis of the actual commercial value of the material. The following analyses show how similar may be the chemical composition of a kaolin, a fire clay, and a ball clay.

Analyses of North Carolina kaolin, fire clay, and ball clay.

[Analyses of kaolin and fire clay by Ries. Analysis of ball clay by Edward Orton.]

Constituent.	North Carolina kaolin.	Fire clay.	Ball clay.
SiO_2	45.40	45.29	48.94
Al_2O_3	37.34	40.36	36.69
Fe_2O_3	1.92	.51	.35
CaO	.44	.037	.47
MgO	.20	.015	.71
Alkalies	.52	.136	1.28
Water of combination	13.96	13.608	12.14
Total	99.78	99.956	100.58

The physical tests show the following results:

Physical tests of North Carolina kaolin, fire clay, and ball clay.

Material	North Carolina kaolin.	Fire clay.	Ball clay.
Shrinkage	*Per cent.*	*Per cent.*	*Per cent.*
	Air 4	Air 6	Air 8
	Fire 8.5	Fire 3	Fire 11
	Total 12.5	Total 9	Total 19
Color	White.	Gray.	Cream.

It is generally understood that the content of iron oxide is a gage of the color of the burned clay, but here is a kaolin with 1.92 per cent oxide of iron burning a pure white, although a fire clay with 0.51 per cent oxide of iron burns gray and a ball clay with 0.35 per cent oxide of iron burns cream.

The shrinkage also shows the same great variation, the ball clay having more than twice the shrinkage of the fire clay and the kaolin falling between them. The tensile strength of these clays varies as greatly as their other properties. In the air-dry state the fire clay will hardly hold itself together and is generally worked with some more plastic clay as a bond. The kaolin may hold 40 to 45 per cent of nonplastic material together, but even when pure it has too little bonding strength and must be handled carefully. The ball clay is remarkably tough and will carry 70 to 80 per cent nonplastic material and produce a strong air-dry product.

From the foregoing statement it is apparent that for the comparison of clays from widely differing sources the chemical analysis has only a limited value. However, where the clays being compared are of similar origin the chemical analysis is of great value and may furnish a means of explaining otherwise unaccountable irregularities. For the processes of chemical analysis of clay see United States Geological Survey Bulletin 422, "The analysis of silicate and carbonate rocks," by W. F. Hillebrand. Manifestly the chemical analysis is valuable only when the samples have been taken so as to fairly represent the deposit.

When, as in the present case, the material under investigation is not completely altered, the rational analysis is a valuable aid. Pure kaolin is known to be decomposed by sulphuric acid, but feldspar and quartz are only slightly, if at all, attacked in a carefully made rational analysis. This difference furnishes a means of dividing the feldspathic material and quartz from the kaolin. Mica, if present, causes confusion because it is decomposed by sulphuric acid and hence is taken out with the kaolin.

RATIONAL ANALYSIS OF CLAY.

BOLLENBACH METHOD.[a]

One gram of the clay is placed in a 400-c. c. Erlenmeyer flask of good glass. Twenty cubic centimeters of water and a few drops of sodium hydroxide are added and the mixture thoroughly cooked. The mixture is cooled rapidly and 10 to 15 c. c. of concentrated sulphuric acid is added cautiously. The flask is shaken vigorously while the acid is being added, to insure its thorough distribution. If the liquid becomes dark in color, indicating the presence of organic matter, 1 to 3 c. c. of nitric acid is added.

The flask should now be covered with a small filter funnel and placed on a sand or air bath, where it will heat very gradually. Particles of clay that in the cooking become attached to the sides of the flask should be returned to the liquid by carefully shaking the flask.

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[a] Bollenbach, H., Rational analysis of clay: Sprechsaal, 1908, No. 25, pp. 340-343, No. 26, pp. 351-354.

Toward the end of the cooking the flask becomes filled with white sulphuric-acid fumes. As soon as the fumes are visible the flask should be removed from the fire. The solution should be carefully diluted with water to three times its volume and cooled. Ammonium hydroxide is added drop by drop, the flask being shaken to insure thorough mixing, until the solution smells distinctly of ammonia or an added indicator shows a permanent alkaline reaction. The precipitate is transferred to a large filter and washed thoroughly with hot water. Dilute hydrochloric acid is added to the precipitate to dissolve the aluminum and iron hydroxides and the calcium and magnesium carbonates. The solution is collected in a 250-c. c. graduated flask, cooled, and filled up to the mark. After thorough shaking, 100 c. c. is drawn off with a pipette and cooked to dryness in a platinum dish. The dry residue is heated one-half hour at 120° C.; any silica that has been taken into solution by the digesting with hydrochloric acid is thus rendered insoluble. After cooling, the residue is moistened with 5 to 10 c. c. of concentrated hydrochloric acid and allowed to stand a few minutes. By adding hot water, the chlorides of aluminum, iron, and calcium are dissolved. The silica is filtered off, washed, ignited, and weighed. The iron and alumina are precipitated from the filtrate by the addition of ammonium hydroxide. The precipitate is filtered off, washed, ignited to constant weight, and weighed as $Al_2O_3+Fe_2O_3$.

In most cases there is no calcium present in the precipitate. Only when the clay contains more than 20 per cent calcium carbonate is a reprecipitation of the alumina and iron necessary. If iron is present in small amount, its separate determination is unnecessary. If present in excess of 1.5 per cent, it should be determined volumetrically in another 100 c. c. of the original solution.

The clay substance is calculated from the amount of Al_2O_3 found. Since only two-fifths of the original gram was used in this determination, it is necessary to multiply the Al_2O_3 found by 6.336 to find the amount of clay substance in the original 1-gram sample.

The calcium may be precipitated from the filtrate after the alumina and iron precipitate has been removed and calculated as lime, or if the ultimate analysis so indicates, as gypsum.

The mica in mica-bearing clays may be calculated from the alkali present, the alkali being determined by the method devised by J. Lawrence Smith.

DETERMINATION OF FELDSPATHIC MATTER BY CALCULATION FROM SILICA PRESENT IN THE SILICEOUS RESIDUE.

The siliceous residue from the sulphuric-acid treatment described above has been carefully washed, dried, and weighed. Five times its weight of normal sodium carbonate is added and is thoroughly mixed in a 20 to 30 gram platinum crucible. The crucible is covered and placed over a small Bunsen flame until the mass is heated through, when the flame may be gradually increased, but care must be taken that no violent boiling occurs. After the fusion is practically complete and the liquid becomes quiet, the crucible should be placed over the blast lamp for a few minutes. Then the crucible is removed from the flame and by carefully tilting it from side to side the mass is distributed over the inside of the crucible and not allowed to solidify in a cake in the bottom. After cooling, the crucible containing the fused material is placed in a beaker with some water and chemically pure hydrochloric acid is added in excess. The beaker is covered and placed on the water bath, where it is digested until disintegration is complete. The contents of the beaker and crucible are now transferred to a platinum or porcelain dish, the particles adhering to the crucible being loosened by the aid of a blunt glass rod. The solution is evaporated to dryness on the water bath, redissolved in concentrated hydrochloric acid, and, after heating 15 minutes, diluted with an equal amount of water and again evaporated to dryness. The dry residue is soaked with hydrochloric acid for 15 minutes, then diluted with an equal amount of water, covered, and placed on the water bath for one-half hour, after which it is diluted with water and filtered. The liquid should be decanted onto the filter and the silica that is left in the bottom of the dish should be washed onto the filter with cold water or dilute hydrochloric acid. After thorough washing with hot water, the silica is removed to a crucible and ignited by a strong blast for 20 to 30 minutes; then cooled and weighed. The calculation of feldspathic matter proceeds as follows:

The original amount of siliceous residue minus the silica just determined gives the flux and alumina present in the feldspar, that is—

$$\text{siliceous residue} - SiO_2 = RO + Al_2O_3.$$

In potash feldspars the following proportion obtains:

$$(RO + Al_2O_3) : \text{feldspar} = 1 : 2.837,$$

and, since the potash feldspar is always used in such calculations, it is only necessary to multiply the difference between the total siliceous residue and the silica as determined by 2.837. The result is the feldspathic matter in the siliceous residue and the remainder of the siliceous residue may safely be considered as free silica.

This method has been employed in ceramic determinations and has been found thoroughly satisfactory where a rational analysis only is desired.

DETERMINATION OF FELDSPATHIC MATTER BY CALCULATION FROM ALUMINA PRESENT IN THE SILICEOUS RESIDUE.

For this determination the same process is followed as for the determination from silica present. The filtrate from the silica, however, is brought to boiling in a large beaker of good glass and NH_4OH is added carefully until the odor indicates an excess. Boiling is continued for a few minutes, the precipitate is allowed to settle, and the alumina and iron oxide are filtered quickly and washed with hot water. In filtering, the precipitate should be allowed to settle and the clear liquid decanted off first, as otherwise the filtering of the alumina is a slow process. The precipitate is dried, ignited, and weighed as $Al_2O_3 + Fe_2O_3$. The iron oxide, if present in large amount, as indicated by a heavy dark-brown precipitate, should be determined separately as outlined in the ultimate analysis, but in most instances it may be safely included with the alumina.

The ratio of the Al_2O_3 to total potash feldspar is 1:5.451.

The feldspar thus calculated is deducted from the total siliceous residue and the difference is considered as free silica.

In case the feldspar present is unaltered, a microscopic investigation will disclose the fact and will also reveal the presence of mica, quartz, and other impurities. The rational analysis indicates the degree of kaolinization in that it divides the soluble from the insoluble portion. The microscopic analysis indicates whether the alkali should be figured as feldspar or as mica, or as neither.

IMPURITIES OF KAOLIN.

Kaolins produced by alteration of the feldspars of the dikes in the region investigated naturally vary more or less because of variations in the composition of the dikes and the extent of kaolinization.

The most serious impurity in these dikes, as in all kaolin deposits, is iron stain, which is present in two forms, as explained in the description of the dikes. The iron stain from infiltrated surface water is not serious, but when iron-bearing gneiss or schists occur as inclosed masses in the kaolinized dike, its removal without contaminating the surrounding material demands great care.

Muscovite alters slowly and it is generally found in the fresh state. Where present as large crystal masses it can be easily removed and made a source of profit in connection with kaolin mining. Where present as very small crystals or where the large masses have been broken by improper mining or refining methods its complete separation from the kaolin is difficult, and its presence may reduce the market value of the kaolin considerably. The separation of this fine mica will be discussed later.

Biotite alters much more readily than muscovite, but in the kaolinized dikes studied it is rarely disintegrated to such an extent as to impair seriously the value of the kaolin. When finely divided or broken into small fragments its separation from the kaolin is as difficult as is the separation of muscovite and its presence affects the market value of kaolin even more seriously than does muscovite.

The iron garnets of the original rock are generally completely altered in the residual mass and show as brown spots in the white finely divided quartz and kaolin. Since their coloring power is enormous the presence of a great number of such spots renders that part of a deposit valueless, since the garnets disintegrate with the kaolin in water and stain the entire product. When not too numerous these brown spots may be removed by hand sorting, which is of course an expensive operation.

REFRACTORY VALUE OF A KAOLIN.

The refractory value of a kaolin is determined by the same method as is used for determining the deformation point of a feldspar. In fact the difference between the two tests is mainly a matter of relative temperatures.

The form used for determining the refractory value is a cone of smaller dimensions than that used for feldspar studies. Its height is 1 inch and the cross section of its base is $\frac{5}{16}$ inch. (See fig. 2, p. 22.) It terminates in a point. The placing and testing of the cones and the recording of the refractory values are the same as set down for the feldspar tests and need not be repeated. Seger cone 35 is pure kaolin and has a deformation temperature of 1,830° C. Crude kaolins, however, rarely possess a deformation temperature as high as this and the purest specimens rarely withstand a higher temperature than cone 34 (1,810° C.), hence it is wise to place cones with deformation temperatures of 1,700° to 1,830° C. in the furnace with the trial, and thus determine at one test what may otherwise require several tests.

Beryl, if present in a kaolin deposit, is not detectable except where the deposit is not completely kaolinized and the crystallization of the beryl renders it noticeable. It seems to display about the same resistance to weathering as does the feldspar.

Tourmaline is not found in any kaolinized dike studied, and no record of its effect on the color of kaolin is available except as stated (see p. 31). If present in a deposit of feldspar or kaolin tourmaline would demand attention and careful removal, as its staining power is about the same as that of biotite mica.

Manganese and cobalt oxides are found directly associated with the kaolin in only one deposit within the region studied and there they are present in such small quantity as not to affect the market value of the deposit.

Aside from the effect on the kaolin of the associated minerals just discussed, the most serious consideration is the effect of the degree of kaolinization. This does not affect the color of the kaolin but does affect its vitrifying and its deformation temperature, its plasticity, and especially its shrinkage. Since the shrinkage must be provided for in making all clay products, any variation in it is a serious matter.

SHRINKAGE.

In the kaolin deposits studied the variation in shrinkage appears to be the most serious hindrance to greater development and for that reason demands careful investigation. Within the region investigated the variation in shrinkage of material from deposits being worked ranges from 6 to 11.4 per cent. An especially selected highly kaolinized sample has a shrinkage of 15.6 per cent.

To prove that the variation in shrinkage is actual and not due to differences in test conditions, commercial samples were taken at the various washing plants. The combined-water content and the degree of fineness were determined, and the samples were made into trials and fired together to cone 6.

The data obtained, which are shown in the accompanying table, prove conclusively that every kaolin in the list has been thoroughly washed. There is no relation, however, between combined-water content and shrinkage, nor between shrinkage and the amount of free water necessary to work the kaolin.

Relative shrinkage of commercial kaolins.

Deposit.	Combined-water content.	Material finer than 200 mesh.				
		Per cent.	Water required to work.	Shrinkage, wet to 110° C.	Shrinkage, 110° C. to 1,250° C.	Total shrinkage.
	Per cent.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
83	12.2	99.10	52	4.8	5.7	10.5
80	12.1	99.73	42	4.0	5.6	9.6
37	12.1	98.01	56	4.4	5.4	9.8
39	12.1	99.73	49	5.0	6.4	11.4
16	12.1	99.73	54	1.0	5.0	6.0
57	13.7	96.72	49	2.6	5.4	8.0

For the purpose of determining whether the shrinkage varies uniformly with depth in a deposit a series of samples was taken at points near the surface of several especially well-exposed deposits. Another series of samples was taken from the lowest accessible mining level of the same deposits. The accompanying table shows the combined-water content, the proportion of the various-sized grains in the sample taken, and the shrinkage at the various stages of manufacture.

Variation of physical properties of kaolins with depth of deposit.

Deposit.	Location in deposit.	Combined-water content.	Coarser than 100 mesh.	Between 100 and 200 mesh.	Material finer than 200 mesh.		
					Shrinkage, wet to 110° C.	Shrinkage, 110° to 1,330° C.	Total shrinkage.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
K3	Bottom	14.20	24.10	8.14	3.6	5.4	9.0
K3	Top	13.00	6.56	10.34	2.8	6.8	9.6
K9	Bottom	12.64	22.51	6.02	5.0	6.8	11.8
K9	Top	11.32	46.80	7.16	6.0	6.4	12.4
K58	Bottom	12.83	82.53	5.07	4.4	7.4	11.8
K58	Top	11.69	75.40	8.29	3.0	4.8	9.8
K12	Bottom	10.00	42.20	8.08	4.4	9.2	13.6
K12	Top	10.33	21.44	5.00	3.6	5.4	9.0
K82	Bottom	11.26	29.52	13.00	3.6	7.6	11.2
K82	Top	11.17	15.30	5.60	4.4	6.0	10.4

A study of this table indicates that there is a marked variation in shrinkage between the top and the deeper portions of these dikes, but in general the variation is not so great as that between different deposits. The variation in deposits is as marked in this series of samples as it is in the commercial samples.

For the purpose of determining the influence of fineness of grain on the shrinkage, a number of samples were washed through a 100-mesh sieve and through a 150-mesh sieve and separated by elutriation. The materials obtained from the samples were made into test wedges and fired at cone 9 for 24 hours.

The results show that one of the kaolins washed through a 100-mesh sieve has a shrinkage of 10 per cent. If washed through a 150-mesh sieve the same kaolin has a shrinkage of 11.6 per cent. If subjected to a floating separation so that 33 per cent of the 150-mesh material is removed, the shrinkage is increased to 12.2 per cent.

Another kaolin treated in a similar manner had a shrinkage of 9.8 per cent when a 100-mesh sieve was used, 12.4 per cent when a 150-mesh sieve was used, and 12.8 per cent when 30 per cent of the coarsest of the material finer than 150-mesh was removed.

These results show the direct effect exerted by size of grain on the shrinkage.

In many deposits all the material passing the 100-mesh sieve is practically pure kaolin, hence it is possible, in case the size of grain may safely be increased, to lessen the shrinkage by using sieves with coarser mesh.

COLOR.

The color of kaolins has never been standardized and hence the classification of samples in regard to color can, for the present, be only temporary. The real values of this classification must be assigned after a standard process has been devised and accepted.

For the present investigation the following process has been chosen as permitting of the easiest correlation to any standard color scale that may be adopted later.

A quantity of kaolin absolutely free from stain of any description from the region examined was selected by careful hand picking. A part was carefully washed in distilled water and made into briquets by identically the same process used in making the samples tested. These briquets were fired with the samples and thus a color standard was provided which for convenience is called grade 1.

The selected kaolin has the following chemical composition:

Composition of kaolin taken to obtain grade 1 color.

H_2O	13.22
SiO_2	46.67
Al_2O_3	39.07
Fe_2O_3	.11
TiO_2	.02
CaO	trace.
MgO	trace.
Na_2O	.11
K_2O	.25
	99.45

A standard English china clay was taken as the standard kaolin against which these kaolins must be checked in standard porcelain mixtures, and this china clay was prepared in a manner similar to that just described and is given a color value of grade 5.

This English china clay has a chemical composition as follows:

Composition of English china clay taken for grade 5 color.

H_2O	12.42
SiO_2	46.86
Al_2O_3	38.10
Fe_2O_3	.30
CaO	.46
MgO	.48
Na_2O	.30
K_2O	1.18
	100.10

The color classification was based upon these two standards and extended beyond grade 5 when necessary.

In order to provide as nearly as possible a uniform surface for the study of the color of the samples, the color trials are all struck off to a smooth surface with a spatula.

The classification of the various sampled kaolins has been accomplished by a series of optical studies. After each study the samples are thoroughly mixed together and the following day again classified.

A classification based on three trials with the same results has been accepted as final.

This method is recognized as faulty because of optical errors, but is the most satisfactory one available pending the establishment of a standard color scale for kaolins.

TENSILE STRENGTH.

The tensile strength of the kaolin is determined in the following manner:

The washed kaolin is mixed with water to form a thick paste, in which condition it is poured on a damp plaster slab. When "leather" dry (approximately 12 per cent moisture) it is cut by means of a sharp die into blanks of the shape and size of a cement briquet, as shown in figure 6.

These blanks are pressed into a standard cement-briquet mold and set away to air-dry. After air-drying the briquets are tested on a standard cement-testing machine for air-dry tensile strength.

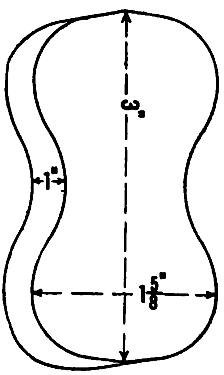


FIGURE 6.—Cement briquet.

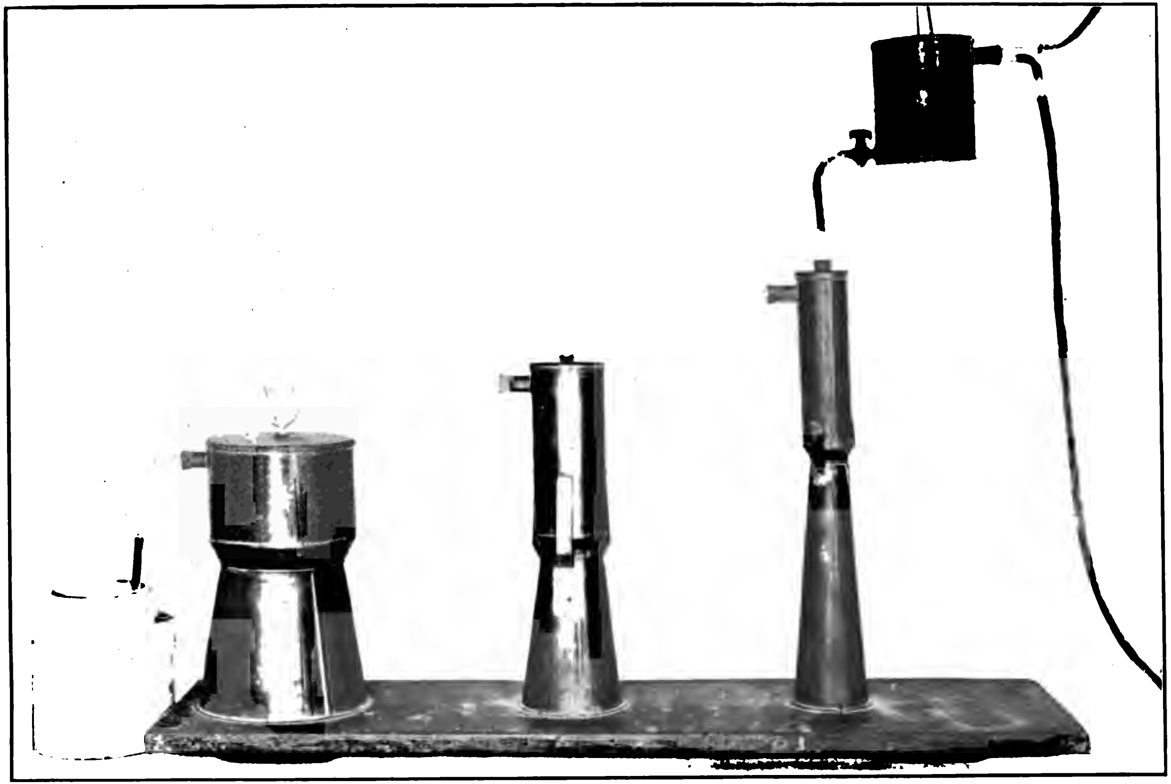
LABORATORY WASHING PROCESS FOR KAOLIN.

In preparing kaolin for testing, the problem is to wash the small samples in the laboratory in such a manner that they may possess the same physical properties as the kaolin from the same deposits washed in a commercial plant. Therefore in order to devise a suitable laboratory process, mechanical analyses were made of crude kaolin from various deposits being worked in the region under investigation. These analyses are compared with mechanical analyses of the washed kaolin from the same deposits.

After an investigation of the various other apparatus for the mechanical analysis of clays, the Schultze apparatus was selected because it is the most readily adjusted and especially because it is simple, so that the average operator can construct and operate such an apparatus if he desires and thus test the deposits that he has sampled before he commences commercial mining.

SCHULTZE ELUTRIATION APPARATUS.

The Schultze elutriation apparatus consists of a series of three jars of diameters 5, 7.5, and 15 c. m., respectively, with conical bases and straight sides. A quantity of kaolin is placed in the smallest jar into the base of which water under a given head is admitted. (See Pl. VII.) The current rising through the jar conveys all particles



SCHULTZE ELUTRIATION APPARATUS.

that it can support into a tube connecting with the base of the second jar. This jar being of greater cross-sectional area, the water rises through it at a slower rate than the water in the first jar. Some of the particles supported by the current in the first jar, and carried over to the second, are too heavy for the weaker current in the second jar and fall to the bottom. The overflow from the second jar is conveyed by a tube to the base of the third jar, which is of greater diameter than the second jar. In this jar the separation of still smaller particles is effected and material fine enough to be supported by the current flowing up through the third jar is conveyed to a fourth jar, where it settles. In this way the original sample is divided into four portions that differ in fineness.

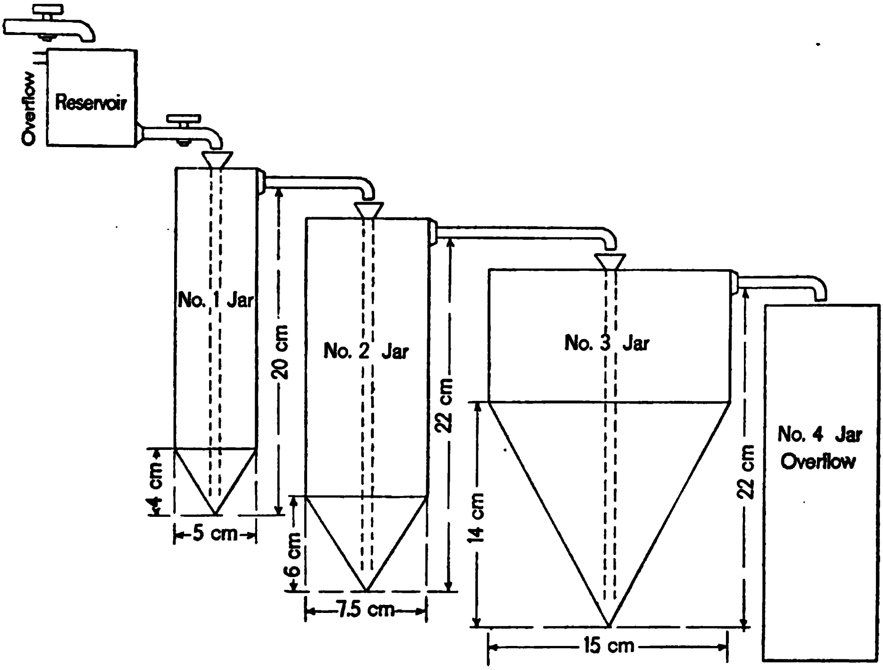


FIGURE 7.—Schultze elutriation apparatus: Flow, 4.4 c. c. per second: hydraulic values, No. 1 jar, 0.225; No. 2 jar, 0.100; No. 3 jar, 0.025.

Since the particles removed by the different jars of this apparatus will be determined by their size, shape, and specific gravity, and also by the rate of flow of water in the apparatus, the various divisions of particles are expressed in hydraulic values.

The hydraulic value of a given particle of any material is the rate of vertical flow of water, expressed in cubic centimeters per second, necessary to sustain that particle in suspension in water.

The hydraulic value is determined as follows:

$$\text{Hydraulic value} = \frac{\text{Volume overflow per second expressed in cubic centimeters.}}{\text{Cross-sectional area of elutriator expressed in square centimeters.}}$$

The Schultze apparatus, when operated with a flow of 4.42 cubic centimeters of water per second, has the following hydraulic values:

Hydraulic values.

No. 1 jar=0.225
No. 2 jar=0.100
No. 3 jar=0.025

The receptacle for maintaining a constant head of water flowing into the first jar is shown above the elutriation jars. A constant head of 50 centimeters (19$\frac{11}{16}$ inches) was maintained for the following investigation, and a flow through the apparatus of 265 cubic centimeters per minute was also maintained.

The material, before introduction into the elutriation apparatus, was passed through a sieve of 200 meshes per linear inch, thus removing all coarse material.

The residues in the different jars were carefully measured and found to vary in the first jar from 0.00205-inch diameter for mica particles to 0.000274-inch diameter for kaolin, quartz, and feldspar particles. In the second jar the residue varied from 0.000685-inch diameter for mica particles to 0.000137-inch for kaolin, quartz, and feldspar particles. In the third jar the residue varied from 0.000274 inch for mica particles to 0.000069-inch for kaolin, quartz, and feldspar particles.

The overflow jar contained particles of a maximum size of 0.000274 inch.

Mechanical analyses of crude and washed kaolins.

Deposit.	200-mesh residue.		No. 1 Schultze residue.		No. 2 Schultze residue.		No. 3 Schultze residue.		No. 4 Schultze residue.	
	Crude.	Washed.	Crude.	Washed.	Crude.	Washed.	Crude.	Washed.	Crude.	Washed.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
83	18.00		8.04		28.55		48.13		15.06	
83		0.895		0.194		17.784		81.465		0.505
80	6.00		6.00		22.39		52.266		20.32	
80		.27		.64		.517		75.26		23.40
16	57.915		9.73		48.60		24.84		16.85	
16		.265		.135		23.82		74.46		1.535
39	27.505		2.11		41.187		52.43		4.257	
39		.265		.817		23.56		74.207		1.397
57	81.05		9.928		50.44		17.578		22.052	
57		3.275		.09		8.618		63.302		28.00
37	9.475		7.02		25.48		67.06		.54	
37		1.99		.92		25.48		72.15		1.50

DISCUSSION OF ANALYSES OF WASHED KAOLINS.

A study of the mechanical analyses of the washed kaolins indicates that only one sample has more than 3 per cent coarser than 200 mesh, or 0.005 inch diameter, and in this sample the very fine material is in excess of any other samples tested. The material remaining in the No. 1 jar is in every case less than 1 per cent and the material remaining in the No. 2 jar is in three cases between 23.5 and 25.5 per cent of the material finer than 0.005 inch diameter.

The proportion of material remaining in the No. 3 jar varies from 72 to 77 per cent with one exception, when it falls to 63 per cent, but this is more than compensated for in this case by the exceptional amount passing over into the No. 4 jar.

Too fine a line of division is not permissible, as is indicated by the study of size of particles in the various jars.

It may therefore be safely assumed that with regard to the proportion of grains of the different sizes the various washed kaolins produced within the district studied do not display any marked variation.

A glance at the mechanical analyses of the crude kaolins indicates that the separation by a 200-mesh screen does not make the product comparable with the washed product in any case. With but one exception the amount of residue in the No. 1 jar is 6 per cent or over and may run as high as 11 per cent, as against less than 1 per cent in the washed product.

The proportion of the crude kaolin that remains in the No. 2 jar is, in all but one case, far in excess of that found in the washed kaolins. Thus it appears that the washing process employed in the region investigated removes practically all that material of the No. 1 jar classification and a considerable amount of that belonging to the No. 2 jar classification. It will be noted that some factory-washed kaolins yield a lower percentage of material in No. 4 jar than is obtained in that jar from crude kaolin of the same deposit. The shortage in No. 4 jar corresponds to an excess in No. 3 jar. This difference may be explained by the fact that throughout this region alum is used as an aid in concentrating the slip; the fine particles are thus coagulated and settle more readily than they would otherwise.

The proportion of the No. 2 jar classification that must be removed in order to obtain absolutely comparable results varies with different deposits; hence the establishment of a uniform process for the duplication of all the washed kaolins is not to be considered and a single uniform process must be accepted and followed for all kaolins.

In order to determine whether the residues in the different jars of the Schultze apparatus vary in physical properties, a quantity of average crude kaolin was screened through a 200-mesh sieve, then mechanically analyzed, and the residues tested. The results were as follows:

Physical tests on Schultze elutriator residues.

	No. 1 jar.	No. 2 jar.	No. 3 jar.	No. 4 jar.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Combined-water content	12.31	13.48	13.37	14.19
Minimum free water for molding	....	56.6	53.3	46.0
Air shrinkage of briquets made with minimum water	....	.6	.6	4.0
Total shrinkage at 1,300° C. of briquets made with minimum water	....	5.4	6.6	12.2

The physical properties apparently do not vary greatly with the size of grain except with regard to shrinkage, and this is excessive only in the very fine material. Provided the percentage content of the No. 4 jar remains constant, any variation in content of the No. 2 and No. 3 jars will not seriously affect results.

A microscopic study of the different divisions of particles indicates that mica is present only in the No. 1 and No. 2 jars, and in No. 2 jar is present only as a few scattered particles. Quartz is also present in No. 1 and No. 2 jars, but its presence in No. 2 jar does not exceed 1 per cent.

Feldspar is present in decreasing quantity from jar No. 1 to jar No. 3, being present in No. 3 only as a few scattered particles that do not show any cleavage lines and are apparently far advanced in kaolinization.

Since the object of washing is merely to remove impurities, and especially those of relatively large dimensions, it seems logical to remove all the coarse material possible by sifting. In commercial operations the sieve is used to supplement elutriating and floating. Thus the plates of mica present in the crude kaolin are treated for a longer time with the kaolin and fine sand and are more broken and pulverized, resulting in a greater amount of fine mica in the finished product than if the sieve were used first.

As a guide to the selection of a sieve for the separation of the coarse particles from kaolin prior to elutriation, sieve tests were run on five kaolins from the region investigated. The data obtained are as follows:

Sieve separations of crude kaolins.

Test.	Residue on 40-mesh sieve.	Residue on 100-mesh sieve.	Residue on 150-mesh sieve.	Residue on 200-mesh sieve.	Material finer than 200-mesh sieve.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
A	61.30	15.93	6.50	2.60	22.67
B	28.14	24.75	6.58	.50	40.03
C	20.00	16.82	15.32	1.75	46.61
D	12.25	21.62	9.30	2.56	54.27
E	....	31.82	5.26	1.24	61.68

From this investigation it appears that the proportion of coarse material removed by a sieve of 200 meshes per linear inch in addition to that removed by a sieve of 150 meshes per linear inch may not be expected to exceed 2.6 per cent, and this additional amount of coarse material would hardly influence the operation of the elutriator. A microscopic study of the residues indicates that both the 150-mesh and the 200-mesh residues consist largely of mica; hence the removal of mica prior to elutriation is desirable. A sieve of 200 meshes per linear inch is recommended by the author and will be used for ensuing investigations. However, the use of a sieve of 150 meshes per linear inch is permissible, and if the crude kaolin contains much rough and coarse material such a sieve will be found much more durable than a finer one.

The operation of an elutriator for washing kaolins is based on the supporting power of a rising current of water, and since the quantity of water necessary increases as the cross-sectional area of the cylinder, it is advisable to use a cylinder of as small diameter as can be operated conveniently. The grade of material removed can be regulated entirely by the velocity or rate of flow of the current of water.

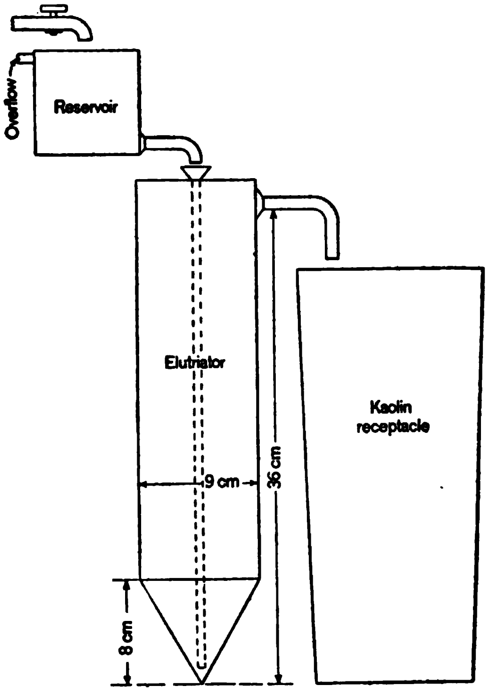


FIGURE 8.—Laboratory elutriator operated at different rates of flow: Flow, 859 c. c. per minute, hydraulic value, 0.225; flow, 800 c. c. per minute, hydraulic value, 0. 209; flow, 700 c. c. per minute, hydraulic value, 0. 153; flow, 650 c. c. per minute, hydraulic value, 0.170; flow, 600 c. c. per minute, hydraulic value, 0.157; flow, 500 c. c. per minute, hydraulic value, 0.131.

The elutriator designed especially for and used in these investigations is shown in figure 8.

The hydraulic value of the smallest particles desired to be removed from the crude kaolin lies between 0.225 and 0.100.

To determine the capacity of this elutriator, it was operated at various hydraulic values between these two extremes, and mechanical analyses of the kaolins obtained were made by means of the standard Schultze elutriator. The results are as follows:

Mechanical analyses of kaolin washed by laboratory elutriator operated at different velocities.

Flow through cylinder per minute.	Hydraulic value.	Mechanical analyses of product by standard Schultze elutriator.			
		No. 1 residue.	No. 2 residue.	No. 3 residue.	No. 4 residue.
C. c.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
859	0.225	5.23	31.38	30.4	33.00
800	.209	2.42	27.31	30.075	40.20
700	.183	2.07	21.31	34.85	41.77
650	.170	.48	19.83	36.18	43.51
600	.157	.02	15.03	36.88	48.07
500	.131	.025	10.17	39.53	50.275

A study of the results shows that for this elutriator a hydraulic value of about 0.170 or 650 cubic centimeters per minute will give a product practically free from particles of the No. 1 Schultze elutriator size and will also remove 37 per cent of the largest particles in the No. 2 Schultze elutriator classification. The product should very closely resemble the average washed kaolin of the region, and the process will be accepted as standard elutriation for these kaolins.

LABORATORY KAOLIN-WASHING PROCESS IN DETAIL.

Based on the foregoing investigations, the following process was worked out as a substitute for the kaolin washing commercially practiced in the region investigated:

One pound (453.6 grams) of the crude kaolin is weighed out and carefully sifted into about 1½ pints (850 c. c.) of distilled water or filtered rain water, and the whole thoroughly stirred and allowed to stand until the kaolin has completely slaked. If the lumps do not slake readily it may be necessary to employ a disintegrator, but this should never be a ball or tumbler mill, as such a mill tends to pulverize the mica present. When the use of a disintegrator is necessary, an agitator with a speed of not over 50 revolutions per minute is recommended.

For laboratory use a modern household churn of small capacity (see *B*, Pl. VI) makes an excellent agitator. The kaolin to be disintegrated should be allowed to stand for an hour in distilled or rain water and then washed into the agitator. The agitator should never be run fast enough to move the large lumps of quartz and mica which have settled to the bottom. When the material on the bottom of the agitator is free from kaolin particles, stirring should cease and the contents of the agitator should be emptied into a porcelain dish or enameled steel pan of suitable capacity.

After standing for a few minutes the coarse material will settle to the bottom, and the kaolin-bearing water may be decanted or poured on a sieve of 150 or 200 meshes per linear inch. If the slip or kaolin-bearing water is slowly poured on the sieve and the latter slightly agitated the slip will pass through without difficulty, leaving the coarse material on the sieve. If, on the other hand, the contents of the agitator are dumped on the sieve at one time, the coarse particles will clog the holes and the operation of the sieve will prove difficult and often impossible without the aid of stirring the sediment on the sieve surface with the hand.. Such hand stirring, or rubbing of material through the sieve, is to be strongly condemned. It not only forces through the sieve particles larger than the normal dimensions of the apertures, but it permanently distorts the apertures, so that the sieve has both large and small openings and is rendered worthless.

After all the particles possible have been shaken through, the sieve should be removed from the dish and placed over another dish or pan, into which it will fit snugly. In this pan should be placed about a pint of water, and by a shaking motion the sieve should be washed from below. Such washing will remove the fine particles much more quickly than placing the water on the sieve with the residue.

The sieve containing the coarser material should be allowed to dry; the coarse material when dry should be weighed and its weight recorded.

The two pans of washings should be mixed. They are then ready for elutriating.

The laboratory elutriator should be adjusted so that exactly 650 cubic centimeters (18.3 ounces) of water passes through the cylinder in a minute. The flow may be regulated by a valve or pinch-cock on the tube that conveys the water from the reservoir to the cylinder. When all is in readiness, the cylinder should be emptied of water and the kaolin sample which has passed the 150 or 200 mesh sieve should be poured into it; the dish in which it was contained should be well rinsed and the rinsings added to the kaolin in the cylinder. The water may then be started and the elutriation begun. The results may easily be irregular if the flow of water varies in the least, and every precaution should be taken to insure a steady flow. The reservoir is for this purpose. Elutriation should continue until the overflow from the cylinder shows no sediment after standing several minutes. The finest portions pass out of the elutriator with the first 8 or 10 liters. As this fine material settles very slowly, it is advisable to keep the first 2 gallons separate from the later flow which contains less fine material and hence settles more quickly. The remainder may be collected into one large receptacle and in a few hours will generally settle, so that practically all the water may be poured or decanted off and the residue added to the receptacle containing the first 2 gallons of the washings, and all stirred thoroughly together.

This material may be pressed free from water by means of a small laboratory filter press. If such apparatus is not available, a satisfactory substitute is a canvas bag about 8 by 14 inches in size, strongly sewed to prevent ripping and provided with a loop for suspension. The kaolin slip after being well agitated is poured into the bag, which is either hung up to drain or pressed free from water by weights. Care should be exercised when the weights are applied to avoid a sudden large increase of pressure, as a leak thus started will be found difficult to stop.

After the water is removed the kaolin has only to be dried and weighed. The residue remaining in the cylinder may also be dried and weighed and this, together with the residue on the sieve, constitutes the waste material of the washing process. The total weight of these three dried residues should equal the weight of the original sample. The weight of dry kaolin obtained by this process should indicate the productiveness of the deposit, provided the sample tested is fairly representative of the deposit.

PROPERTIES OF KAOLIN IN PORCELAIN MIXTURES.

The rôle of kaolin in all pottery mixtures is that of a plastic bond in the forming of waves and its bonding action continues through the drying process. In firing, the kaolin, by its high refractory value and its resistance to the solvent action of the feldspar, enables the mass to retain its form, although the particles of kaolin may be enveloped in fluid feldspar so completely that the mass becomes translucent and appears homogeneous. Hence the testing of kaolins in porcelain mixtures must consist of tensile tests and translucency tests in addition to the determination of vitrification range, color, and shrinkage.

For kaolin tests in pottery mixtures, the same proportions of material are used as for feldspar tests in pottery mixtures, that is—

Pottery mixture for kaolin tests.

Feldspar, 20 parts by weight.
Quartz, 30 parts by weight.
Kaolin, 50 parts by weight.

The feldspar and quartz are standard materials and the kaolin is the material being tested. The materials are all in the form of impalpable powders and are mixed together with just enough water to produce a plastic mass capable of being formed as desired. The mass must be thoroughly mixed to homogeneity, as otherwise the product is worthless.

TENSILE TEST.

For tensile tests the method of testing is the same as outlined for tensile tests of the kaolin alone. The tensile strength of the kaolins investigated is so low that when it is reduced by the addition of nonplastic feldspar and quartz the briquets are too weak to support the clamps for testing. Hence such a test is impossible unless some plastic clay is added to give strength to the mixture, and in that event a test would represent the bonding strength of the added clay, so that for the particular kaolins under investigation no tensile test in pottery mixtures is practical. This statement is not to be considered as applying to kaolins generally, as most kaolins possess measurable tensile strength, and this is an important factor in considering the amount of plastic clay that must be added in order to produce an industrially valuable mixture.

TRANSLUCENCY TEST.

For translucency tests the process outlined for a similar test of feldspar is recommended. The test mixture described above is molded into wedges which are fired to the maturing temperature of the standard feldspar and tested by determination of the maximum thickness, expressed in centimeters, at which can be detected a No. 20 wire on the face of the trial next the lamp with the lamp 3 inches distant from the trial. This test is very important, for American kaolins vary greatly in the property of producing translucent bodies with a given mixture of standard feldspar and quartz, and in the color they impart to such bodies. Some kaolins produce pottery bodies which are white both in reflected and in transmitted light, but most American kaolins produce pottery bodies which are pale cream in reflected light and a decided cream in transmitted light.

VITRIFICATION RANGE AND ABSORPTION.

The kaolins investigated do not produce nonabsorbent porcelains at commercial temperatures, hence the absorption at 1,350° C. is substituted for the vitrification range.

THE GRADING OF COLOR.

The grading of color of the kaolins in standard porcelain mixtures has been accomplished by comparison and the most absolute white, free from tint, that was obtained in this investigation is given a value of 1. The standard trial, which to all intents and purposes is pure white, has been given a value of 5, the other kaolins when used in the porcelain mixtures receiving the value based on the class in which they fall by ordinary optical study.

SHRINKAGE.

To determine shrinkage the wedges are measured before and after drying and after firing, or preferably a die of known length is lightly impressed in the face of the newly made briquets or wedges. By measuring these impressions after drying and burning, the shrinkage can be easily and quickly determined.

TESTS UNDER GLAZE.

Since the color of a kaolin under glaze can not be predicted from the color unglazed, the glazing of kaolins in order to determine their industrial value is very important.

It is advisable to use test pieces of the sample kaolins in the standard porcelain mixture. These test pieces have previously been fired to vitrification and any fault in color of the kaolin is intensified. The same glazes are used for these tests of kaolins as are specified for similar tests of feldspars in the porcelain mixture. The glazing of these trial pieces demands extra care since vitreous porcelain has smooth surfaces, and unless great care is exercised and the glaze is very thick the greater portion of the glaze will run off the trial or at least mix with the other glaze test on the same trial piece. Warming the trials is a great aid in preventing this difficulty. In firing these glazed trials the same care must be exercised as with the glazed feldspar trials or the glazes on fusing will run off the trials or run together.

BLANK OR STANDARD TRIAL FOR KAOLIN.

The blank or standard trial for kaolin consists of the standard porcelain mixture and contains the standard feldspar, kaolin, and quartz in the proportions specified.

The standard kaolin used is an English china clay having the following composition:

Composition of English china clay used for standard kaolin.

Combined water	12.42
SiO_2	46.86
Al_2O_3	38.10
Fe_2O_3	.30
TiO_2	.00
CaO	.46
MgO	.48
K_2O	1.18
Na_2O	.30
	100.10

This kaolin has a refractory value of 1,690° C., and burns to a porous white mass at 1,350° C.

Properties in standard porcelain mixture.

In the standard porcelain mixture in which this kaolin is used the mass becomes vitreous at 1,310° C. The color is a vitreous white of grade 5. The translucency is 0.65 and the total shrinkage is 15.6 per cent, which consists of 3 per cent drying and 12.6 per cent firing shrinkage.

QUARTZ.

Quartz theoretically is pure crystalline silica, but in nature it is rarely found absolutely pure. The dikes studied contain sugar, smoky, and transparent quartz.

The sugar quartz is most abundant and is most widely distributed, being common throughout the region investigated. It generally forms the outside bands of a dike and also the quartz band or lens along the middle of many dikes. Some bands of sugar quartz are 4 to 12 feet wide and hundreds of yards long. It is seldom sufficiently disintegrated to fall to pieces, but often has to be broken with a sledge or an explosive before it is reduced to pieces of convenient size for handling. It is crystalline, pure white, and opaque, due to innumerable vesicles of gas liberated at the time of crystallization and to fractures subsequent to crystallization. It is practically pure silica, showing by analysis an average of 99.3 per cent SiO_2.

Smoky quartz is found only in the vicinity of Sprucepine, Mitchell County, N. C. Wherever present it is in narrow bands or lenses in the pegmatite and not in an outside band adjoining the country rock. It is invariably badly ruptured, being easily broken by the fingers into small needle-like particles with sharp edges. It consists of an aggregate of particles of varying color intensity and in the mass presents a mottled appearance. The smoky tint has a decided brown cast in some particles, whereas in other particles it tends to an amethystine purple. Some writers state that this color is due to the presence of manganese; others that it is due to the presence of organic matter. Whatever may be the source of the color it disappears completely at between 350° and 400° C. When a solid piece of this smoky quartz is heated, the color fades uniformly throughout. By heating smoky quartz, A. W. Wright[a] obtained a gas of the composition CO_2, 98.33 per cent, and N_2, 1.67 per cent. On further heating this gas gave a brown precipitate which partly dissolves in alcohol. By more intense heating this brown residue volatilizes with a strong bituminous odor similar to that given off by burning cannel coal. The quartz residue is pure white. This smoky quartz, therefore, may safely be looked on as a colorless quartz so far as its influence in ceramic mixtures is concerned.

The transparent quartz is found in this district only as a component of pegmatite. It exists as quartz grains intermixed with the feldspathic material and in most instances is so intergrown with the feldspar that separation is impossible. The specific gravity of quartz is 2.65; the specific gravity of potash feldspar is 2.54, and of soda feldspar 2.60, which may be increased by the presence of calcium in the feldspar. Hence a successful mechanical separation is impossible.

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[a] Am. Jour. Sci., vol. 21, 1881, art. 24.

The transparent quartz separated in the washing of kaolin is generally so mixed with mica and other impurities that its recovery by cleaning would not be commercially practicable.

The sugar quartz is therefore the only pure silica present in commercial quantity in the region investigated. When pure its refractory value is cone 34 (1,810° C.). With the small amount of impurity present its deformation point or refractory value is about cone 32 or 33, that is, 1,780° C.

COLOR.

Fired alone to cone 12 the quartz gives a pure white opaque mass with no strength and no trace of cementing action.

In mixtures with pure feldspar (microcline) the quartz opacifies the feldspar, apparently due to finely divided quartz in suspension.

When added to mixtures of feldspar and kaolin the quartz changes the color in vitreous ware from blue white to pure white, and at the same time tends to change the texture from glassy to granular without, however, reducing the translucency of the mass. In fact, additions of ground quartz up to a given quantity for a given temperature tend to increase translucency. The mechanical strength of a vitreous body is increased by additions of ground quartz up to a given quantity, dependent on the maturing temperature of the body.

SEMIKAOLINIZED FELDSPARS.

The name "semikaolinized feldspar" is used to designate all those deposits of material that have so altered that they can no longer be classified as fresh feldspar but on the other hand have developed no plasticity and hence can not be classified as kaolin.

The location of the deposits of such material is divided into two classes, (*a*) isolated bands, (*b*) semikaolinized dikes.

(*a*) In kaolinized dikes containing many bands of widely differing material there are always found one or more bands that have withstood weathering and that produce no kaolin. Such bands are invariably found to consist of semikaolinized feldspar. These bands are lenticular and the presence of a broad exposure of such material is no indication that all the surface of the dike will consist of this material.

In dikes containing semikaolinized material, the mining of the kaolin necessitates the removal of these hard bands and heretofore they have been thrown aside as refuse together with quartz bowlders and other undesirable foreign material.

(*b*) In dikes that are apparently completely kaolinized on the surface, mining to about 100 feet exposes less altered material, and the degree of kaolinization decreases with depth until fresh feldspar is reached. Thus in such dikes the semikaolinized feldspar lies below the kaolin and above the fresh feldspar. Although its alkali content increases downward the variation is generally not so abrupt as to cause difficulty, and with care in mining and with proper mixing of the mined material a uniform product should be easily produced.

This semikaolinized feldspar is peculiar in that in 16 such deposits sampled no semikaolinized soda feldspar was found, every deposit being potash feldspar with a maximum soda (Na_2O) content of 1.11 per cent. Furthermore, the potash (K_2O) content is higher than in most feldspar, being 14.40 per cent in one specimen, and the alumina (Al_2O_3) content is invariably higher than is theoretically required either in the potash or soda feldspar.

The foregoing observations seem to justify the conclusion that these semikaolinized feldspars found in lenses or bands in an otherwise kaolinized dike represent a material that contains more potash and alumina than the associated bands and, being more resistant to weathering, has remained only slightly altered while the remainder of the dike has completely broken down.

The presence of an excess of Al_2O_3 and also the presence of combined water indicates the progress of weathering and doubtless the giving up of some alkali. The fact that no fresh feldspar that carries more potash than these semikaolinized feldspars is found in this district would indicate that weathering has removed the Na_2O, if any alkali has been removed. This removal of the soda portion of the feldspar before that of the potash portion might be expected from the weaker resistance to weathering of soda feldspars.

The semikaolinized material below the upper kaolinized part of the dikes also shows this high potash content and low soda content. Here is additional proof that weathering has affected the soda-bearing material first.

Examination of the kaolin above the semikaolinized part of a deposit fails to disclose more than a small percentage of Na_2O, the K_2O content always being in excess, hence the Na_2O, if leached out, must have been completely removed from the dike.

The potash content, in the samples taken, varies from 1.7 to 14.4 per cent K_2O, the amount of combined water varying inversely as the alkali content. As the samples were taken to represent the average composition of the portion of the dike sampled, no information as to the rate of alteration can be obtained from their study but the data at hand indicate that in deposits containing 50 per cent or more of the original alkali content the proportion of combined water present may be taken as a fair criterion of the proportion of alkali removed.

The alkali content would be expected to control the deformation temperature provided the other ingredients remain reasonably constant. Although a small change in alkali content seemingly affects the deformation temperature only slightly, the combined water content is a reliable indicator of the deformation point of the semikaolinized feldspar. Thus it appears that the change in deformation temperature is due not only to the proportion of alkali and other elements present, but also to the mineral form in which these elements exist. Figure 9 indicates the consistent increase in deformation temperature with increased combined-water content. In this figure are plotted data from 10 of the best exposed deposits coming under this classification.

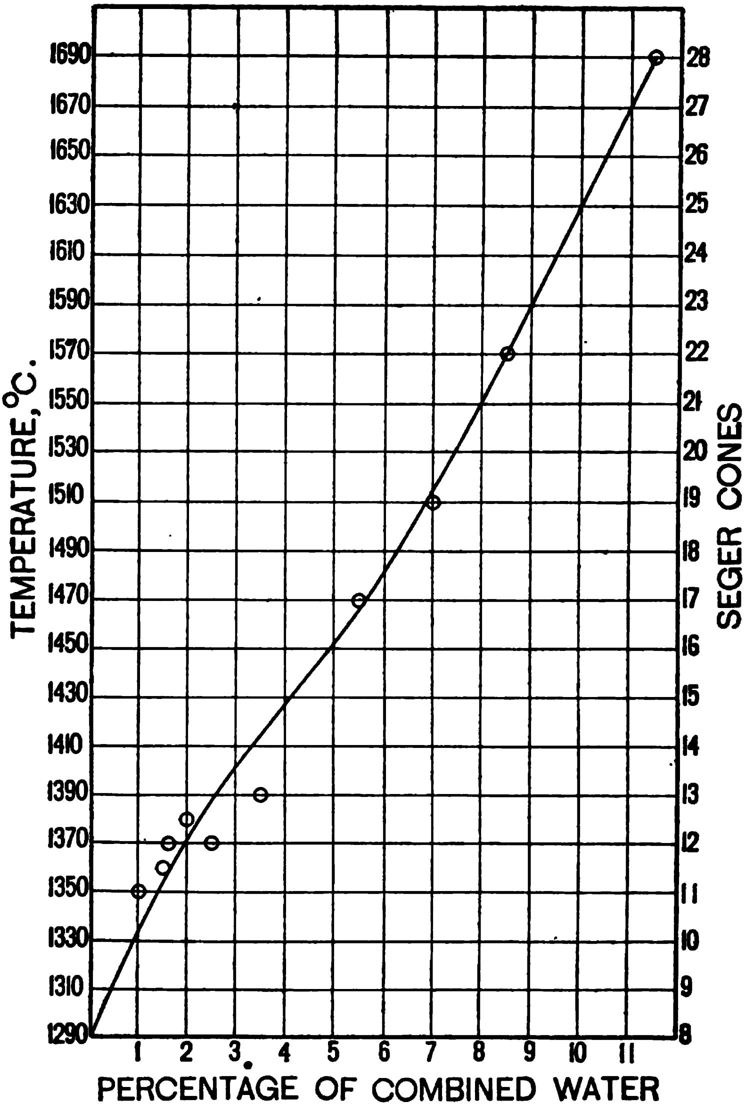


FIGURE 9.—The deformation temperature of semikaolinized feldspar plotted against the combined-water content.

The lack of better agreement is doubtless due to the fact that when a dike is exposed to the elements for any time the alkalies leach from its surface and the taking of representative samples is rendered difficult, even though the surface material be removed for several feet.

A peculiarity of all these semikaolinized feldspars is their gradual deformation. The softest of the specimens tested were vitreous and highly translucent for 50° C. before they deformed. Some of the harder specimens were vitreous for almost 100 degrees.

Another physical property to be considered in connection with a study of these materials is shrinkage in firing. When fired at 1,330° C. the specimens that are only slightly kaolinized shrink 15 per cent. With greater kaolinite content the shrinkage decreases, until in specimens containing 60 per cent kaolinite the shrinkage is only 10.75 per cent. With increased kaolinite content the shrinkage increases again, until in specimens showing a content of 14 per cent combined water but no plasticity the shrinkage ranges from 12.5 to 15.25 per cent.

This peculiarity in shrinkage is explained as follows: In the slightly kaolinized specimens the excessive shrinkage results from vitrification, whereas in the specimens nearing complete kaolinization the shrinkage is due to the grains being very fine.

The deposits containing little or no alkali, but having no plasticity and forming the refractory end of this series, can possess little or no interest for the ceramist owing to their great shrinkage.

For the deposits containing one-half or more of their original alkali content, a ready market should be found in the pottery industry. The majority of these semikaolinized feldspars may be crumbled in the fingers, and at best a very light grinding would suffice to reduce the material to an impalpable powder. Thus the cost of grinding would be only a small proportion of the ordinary cost. An additional advantage of these materials is their pure color, which should make them especially suitable for raising the quality of cheaper soda feldspars that are too much colored to be easily marketable.

These semikaolinized feldspars are merely mixtures of the materials ordinarily employed in pottery bodies, and in some instances the plasticity of the fully developed kaolin is the only essential lacking in order to produce a perfect porcelain.

For example, a semikaolinized feldspar has the following chemical composition:

Composition of a semikaolinized feldspar.

H_2O	2.78
SiO_2	64.59
Al_2O_3	20.80
K_2O	11.83
	100.00

Recalculation to mineral components gives the following composition by weight:

Mineral components of a semikaolinized feldspar.

Component.	K_2O.	Al_2O_3.	SiO_2.	H_2O.	Percentage of total.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	
Analysis	11.83	20.80	64.59	2.78	100
Feldspar	11.83	12.84	45.33	....	70
		7.96	19.26	2.78	
Kaolinite	....	7.96	9.26	2.78	20
Quartz	....	....	10.00	....	10

Thus it is apparent that this material, which has a chemical composition unlike any regularly employed feldspar, is really merely a mixture of 70 parts microcline feldspar, 20 parts kaolinite, and 10 parts quartz, or flint. In fact, the production of a feldspar free from impurity or associated minerals is very difficult and expensive, and very little feldspar is sold that does not contain an appreciable amount of free quartz; hence the kaolinite component is the only new factor introduced.

SUBSTITUTION OF SEMIKAOLINIZED FELDSPARS FOR FELDSPARS.

Although the value of semikaolinized feldspar, as a substitute for feldspar in pottery, has never been exploited, it should be one of the most valuable products of these dikes. It contains practically pure potash feldspar, and if the small amount of kaolin and free silica present is taken into account in the compounding of the body it can be readily seen that a porcelain of longer heat range could be produced than is possible where the ordinary mixed potash and soda feldspar of commerce is used. The color of these semikaolinized feldspars is generally superior to the feldspars of commerce.

For example, let us consider a porcelain of the following composition by weight:

Feldspar	16
Kaolin	45
Flint	39
	100

If a semikaolinized feldspar of the composition

Feldspar	70
Kaolin	20
Free silica or flint	10
	100

is used, the 16 per cent of feldspar in the porcelain is to be supplied by 70 per cent of the semikaolinized feldspar, the kaolin thus introduced being $\frac{20}{70}$ of 16 or 4.57 per cent and the flint $\frac{10}{70}$ of 16 or 2.29 per cent. The total semikaolinized feldspar being thus $16+4.57+2.29=22.86$ per cent semikaolinized feldspar. The 45 per cent of kaolin in the body composition is reduced thus 4.57 per cent, which leaves 40.43 per cent to be introduced as pure kaolin. The flint or free silica in the body composition is 39 per cent, but 2.29 per cent is introduced in the semikaolinized feldspar, hence there remains to be introduced as flint 36.71 per cent. The mixture for the porcelain mentioned above will thus be made up as follows, by weight:

Semikaolinized feldspar	22.86
Kaolin	40.43
Flint	36.71
	100.00

This simple recalculation shows that these semikaolinized feldspars may be made a valuable addition to American ceramic materials. It must be borne in mind that the feldspar thus introduced is potash feldspar and it must replace potash feldspar only. In case the feldspar to be replaced is a mixed potash and soda feldspar, this semikaolinized feldspar should be used to replace the potash feldspar only and soda feldspar should be used to replace the soda feldspar. This replacement can be made with considerable saving, because soda feldspar has a lower market value than potash feldspar.

The use of this semikaolinized material would require the making of careful and thorough tests before its introduction, but to the technically trained man the substitution of this material for commercial feldspar is a simple problem, and the advantages to be gained by the improvement in color and increased heat range would more than repay any inconvenience caused.

The tests for vitrification range, color, shrinkage, and translucency, when this material is substituted for a feldspar, should be made in the same manner as in testing a feldspar.

When it is hoped to substitute some of the more refractory semikaolinized material, only the least plastic kaolin should be replaced and great caution should be taken lest the mixture be made too friable and weak after drying.

Another market for this material, which contains a considerable amount of potash, may arise if potash is ever commercially extracted from feldspar.

MINING AND REFINING THE PRODUCTS OF THE PEGMATITE DIKES.

FELDSPAR.

MINING BY OPEN-CUT.

The mining of feldspar by open-cut is the simplest form of quarrying. The dike is exposed by removing the overburden along a slope and the material is broken down by wedging where practical but usually by drilling and then blasting with dynamite. The different bands of the dike are generally well defined, and hence there is no difficulty in selecting material and the elimination of any undesirable bands is left until the material is sorted for shipment. The wall rock of the fresh feldspar dike is generally solid and no danger of slides exists except where walls are loosened by blasting. The open-cut is generally kept level to the face of the hill to facilitate drainage even though the quarry products are necessarily removed from a higher point. When the quarry extends below the outlet level, pumps are used to handle the water. No difficulty is encountered, since the water is allowed to drain into a central pool, where it settles before it is pumped. (See *B*, Pl. V, and *A*, Pl. VIII.)

The products of the dike are removed by wheelbarrow or by horse and cart to a point outside the quarry where sorting and cobbing are carried on.

TUNNELING AND STOPING.

Where feldspar alone is the product of a dike, tunneling and stoping have never been used within the district under investigation, but where mica is found in paying quantity in the dike, this method of mining is not uncommon. The practice is to run a drift or tunnel into the dike at as low a level as convenient. This drift is continued along the dike until the latter pinches out or the mica becomes too poor and scarce for mining. A vertical cut is then made just inside of the point where the tunnel cuts the dike. This is sometimes carried up for about 12 feet in order to give two benches for working, although ordinary practice in this district is not to work more than 6 feet high at a time. This bench is cut out directly above the old tunnel and when the material is all removed another bench is cut above. In order to facilitate mining, it is customary to build "lofts" of rough timbers above two or three benches and upon them to build platforms for reaching the dike material. Mining is done almost exclusively by drilling and blasting and only the valuable material is removed from the mines, the refuse being dumped into the worked-out area below or heaped in abandoned "lofts."

By thus working from below, the maximum efficiency of the explosives is obtained and the cost of mining is kept low. The drainage

A. OPEN-CUT MINING FOR MICA IN A PEGMATITE DIKE, BOTH WALLS BEING SOLID ROCK.

B. OPEN-CUT MINING FOR KAOLIN. THIS DIKE CONTAINS NO QUARTZ BANDS, DIFFERING THEREIN FROM MOST DIKES IN THIS DISTRICT.

of the mine is natural, since the entrance tunnel is the lowest point opened. Where the feldspar is removed from such workings an ordinary mine car is employed, running on a track to the point where stoping begins. The material is generally dumped from above into a hopper built at this point.

REFINING.

Where the dike contains an excessive proportion of quartz or when the feldspar mined must be of extra quality, the dike product is all hand sorted as cobbed. In cobbing the feldspar is cleaned of all quartz and other associated minerals by means of light hammers and the pure feldspar in irregular lumps is ready for crushing and pulverizing.

CRUSHING AND PULVERIZING.

Crushing and pulverizing is a simple process. If the feldspar is slightly altered it is occasionally calcined to remove the combined water, but ordinarily it is broken with sledges or with a jaw crusher to about 2-inch sizes and fed into a "chaser" mill. This mill consists of two buhrstone wheels 3 to 5 feet in diameter and about 1 foot thick, which are attached to the ends of a horizontal axle that is pivoted in the center. The wheels travel around on a buhrstone bed and the feldspar is crushed between the bed and the wheels. The crushed material is screened and the coarse material returned to the chaser mill, while the fine material is fed to ball mills. The latter are steel-barrel tumbler mills 6 to 7 feet long and of about the same diameter. They are lined with hard wood or silica blocks and are charged with French flint pebbles 2 to 3 inches in diameter. The revolving of the mill causes the pebbles to roll or slide, thus pulverizing the feldspar.

The pulverized feldspar is rarely screened, but the degree of fineness is determined by testing small samples of the material, and the length of the grinding period is depended on to give the desired pulverization. If the pegmatite carries mica the pulverized material should be screened through a fine sieve to remove any unpulverized material.

KAOLINS.

REMOVAL OF OVERBURDEN.

Removal of the overburden is one of the most important and at the same time one of the most neglected details of kaolin mining in the Southern Appalachian region. The method commonly used is to remove just enough overburden to expose the dike and to proceed at once to mine the kaolin. No provision is made for removing surface water during rains, and the invariable result is that more or less overburden is washed into the excavation, staining the walls and otherwise reducing the value of the kaolin in the upper part of the deposit. As the dikes in this region generally dip from 70 to 80 degrees from the horizontal and often toward higher ground, due provision must be made in removing overburden if the upper portion of the dike is to be mined by open-cut, so that the walls need not be too nearly vertical or undercutting become necessary in order to mine all the dike material.

The nature of the overburden influences greatly its tendency to slide and wash, but throughout the region it has been found advisable to slope all overburden walls not less than 30 degrees from the vertical. A level space equal to at least one-half the thickness of the overburden should be maintained around shafts as a protection against slides. This space should never be less than 10 feet wide in order to provide for the safe and economical handling of timbering material for the shafts and for dumping buckets of mine products well away from the shaft mouth.

The method of drainage found most efficient and economical is an ordinary ditch dug as close to the foot of the overburden walls as safety permits. This ditch should be at least 1 foot deep. It should be cut starting in a V above the last-opened shaft and follow the two walls to a point far enough beyond the operating shafts to insure the flow of surface water into a natural drainage way without soaking or running into a refilled shaft and thence into the part of the dike being worked. Much of the present trouble from water in shaft mining could be eliminated by providing and maintaining proper surface drainage. In removing overburden, it is never advisable to remove material much below the top of the dike, even though the material be much stained, because the dike material is loose and will allow surface water to seep down from the drainage ditches. Where the overburden is very porous it may prove advisable to place wooden troughs in the drainage ditches and to fill in closely on the bank side to insure the surface water running into the trough.

MINING KAOLINS FROM DIKES.

In the region studied kaolin is mined by two methods, namely (*a*) open-cut and (*b*) shaft mining.

In most cases the most economical results are obtained by combining the two methods, mining by open-cut for 20 to 30 feet next to the surface and by shaft below.

KAOLIN MINING BY OPEN-CUT.

Where the inclosing walls are solid and the dike is nearly vertical, it is sometimes practical to mine the entire deposit by open-cut, especially if the overburden is thin and the deposit follows the face of a hill. The kaolin can thus be worked in benches and handled by carts with much more economy than by shaft mining. (See *B*, Pl. VIII.) Removal of overburden well beyond the area of operation and careful sloping of the walls of the cut will leave little danger from slides. It must be borne in mind that in such an operation the dike is attacked from the side and not across the face, and in order to obtain a uniform product every bench must be worked across its entire width at the same time.

A more economical method of open-cut mining and one that is more certain to bring satisfactory results is to remove the wall rock on the lower side and thus expose the dike from the top to the lowest workable level. The dike is then cut through its entire width from top to bottom and benching proceeds on the two sides of this cut or, if advisable, on one side only. (See *A*, Pl. IX.) The drawback to this method is the high cost of exposing the dike from top to bottom in case the depth of mining reaches or exceeds 80 feet and the slope of the hill does not exceed 45 degrees. Many dikes are only 10 to 12 feet wide, so that the expense of removing the great quantities of wall rock in order to reach the kaolin becomes too great in proportion to the value of the product. Moreover some expense will also be incurred in open-cutting by reason of the necessity of sloping the back of the cut after the dike has been removed in order to prevent slides. The cost of removing the wall rock and of sloping the wall of the uphill side of the cut must be placed against the cost of timber and timbering in shafts and the other items incident to shaft mining in considering the mining methods to be adopted at a dike.

Mining by open-cut demands the removal of much more associated material than does shaft mining and is to be considered when a sufficient cash outlay is possible to provide the necessary equipment for the economical removal and transport of the refuse.

KAOLIN MINING BY SHAFT.

Where the shaft method alone is used the only surface preparation necessary is provision for diverting surface water from the shafts. At many mines no overburden is removed although at some the removal of part of the overburden is advisable in order to obtain a level area about the shaft mouth. The shafts in this region vary from 14 to 20 feet in diameter and from 40 to 110 feet in depth.

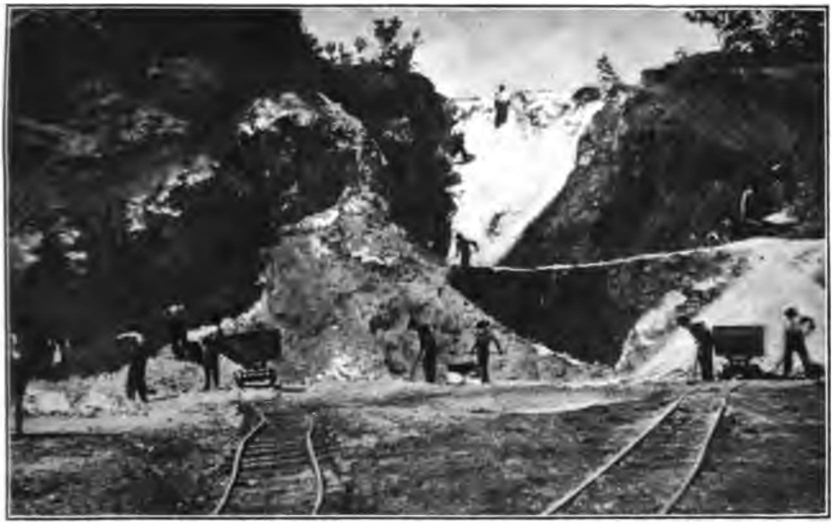
The proper place for a shaft in a dike is a matter to be decided by the operator, but since the majority of the dikes dip 70 to 80 degrees and are only 10 to 20 feet wide, the general practice is to start the shaft in the hanging wall adjacent to the dike, so that the shaft cuts the dike on the hanging-wall side 2 or 3 feet below the surface, and on the footwall side from 50 to 75 feet below the surface according to the dip of the dike. Such procedure often necessitates the removal and handling of an amount of waste equal to or greater than the amount of dike material handled, but sinking and timbering a vertical shaft is so much simpler than sinking and timbering a slope that the operators throughout this district employ the shaft system exclusively. The dike material and the disintegrated gneiss that forms the walls are both friable, so that timbering has to be placed as rapidly as the shaft is sunk.

Sinking is done in the following manner: The shaft is sunk 4 feet, carefully trimmed to form a circle of the desired diameter, and timbering, which is really the most important part of the process, is begun. (See *A*, Pl. X.) The timbers are of yellow pine or oak; they are 4 by 6 inches and generally 30 inches long, and are beveled on the ends to form key blocks. The timbers are placed beginning at the bottom of the 4-foot hole, and the joints are staggered as in bricklaying, thus forming a solid structure. (See *B*, Pl. IX.) Every fourth ring of timbers is spiked to the next lower ring in order to prevent any tendency to twist. When the timbers of the first level are in place, the shaft is dug 4 feet deeper, the timbering in place being supported by the material immediately below it, which is left in place until all other material has been removed. This material is next removed and the timbering is supported temporarily by short props while the next set of timbers is placed.

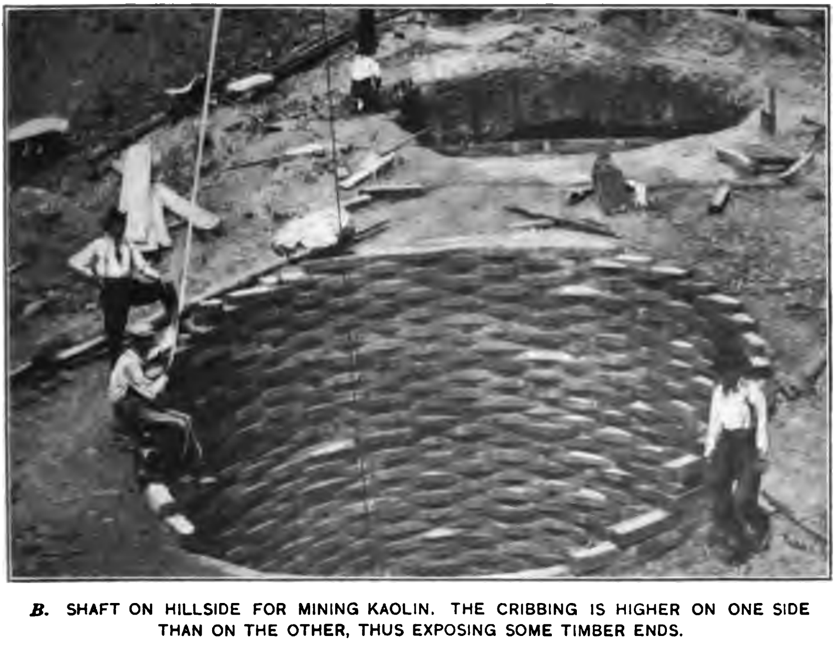
In placing these key blocks the final block completing a circle is put in by digging away the rock wall for a few inches, thus permitting the key to be placed from behind. The opening behind this block is then filled with waste and packed to prevent the block from kicking out. When the timbering has reached the bottom ring of the set above such packing is impossible, hence the final key block for the top ring of each set is cut 4 inches short, and after being placed, a short piece of 4-inch by 4-inch timber is driven into the opening left and is spiked tight. Sinking then proceeds as before. Each 4-foot slice of timbering always being placed as soon as the material from a level is removed.

Owing to the danger of contamination by contact with the iron-stained material constituting the walls of the dikes, the removal of the kaolin should not proceed simultaneously with the removal of wall rock. The kaolin in a given level should be carefully removed and sent to the surface before the wall rock of that level is disturbed. This is not the practice in all mines, but is followed in most shaft mines.

Where a dike incloses small lenses of waste material these should not be disturbed while kaolin is being mined, but should be taken out separately, as they generally contain much iron oxide, and a large amount of valuable kaolin may be injured by mixture with a little of the waste. Different buckets are generally used for handling kaolin and waste.



A. OPEN-CUT MINING FOR KAOLIN, SHOWING BENCH MINING AND THE DUMP-CAR SYSTEM.



B. SHAFT ON HILLSIDE FOR MINING KAOLIN. THE CRIBBING IS HIGHER ON ONE SIDE THAN ON THE OTHER, THUS EXPOSING SOME TIMBER ENDS.

One of the greatest difficulties in shaft mining is the removal of the quartz lenses that are sometimes found along the middle of a dike and which must be removed from within the shaft area. The use of explosives is unsatisfactory because the quartz is more or less fractured, making the successful placing of a shot difficult. Breaking the quartz by sledge is slow and expensive, but has been found the safest and most economical method.

When a shaft has reached the lowest level at which the dike yields kaolin in commercial quantities, robbing and filling begin. Short tunnels are run into the dike from the bottom of the shaft. When the valuable material has been mined by these tunnels as far as is considered safe without timbering, the pillars between the tunnels are carefully removed and the area which has been emptied of kaolin, both within and without the shaft, is filled with waste from adjacent shafts or with that which was stored on the surface when the shaft was sunk.

As soon as a level has been thus robbed and filled the timbering from the level next above is removed and that level is robbed and filled in the same manner. The operation is continued level by level until the surface is reached. In this way every pound of kaolin is removed, and since the shaft timbers are recovered the cost of mining by this process is reduced to the minimum.

For hoisting at shafts ordinary derricks are used throughout the region. Masts and booms are made from native timber with the ends banded to prevent splitting.

The type of bucket used holds about 500 pounds of dike material and is made from an oil barrel by cutting off the upper third. For hoisting water a whole oil barrel is used. A substantial wrought-iron hoop is placed about the bulge; a broad wrought-iron band, which passes under the bottom, is fastened to this hoop, and at these joints the handle of the bucket is connected. (See *B*, Pl. X.) To hold the bucket upright a heavy iron peg is attached to its side and extends above its rim. A heavy wrought-iron ring that encircles the handle of the bucket drops over this peg. The bucket is dumped by lifting this ring. The center of gravity of the bucket is so near the points where the handles are attached that the bucket dumps easily.

The drum hoists are exclusively used at shafts. In some cases horse power is used, but steam-driven hoists are used at the majority of mines. At one mine electricity has been used for operating hoists, and has proved very satisfactory.

Masts and booms of native timber are generally employed and cables are of ⅝-inch stranded steel. Guys are generally of ⅜-inch stranded steel.

COMBINATION OF OPEN-CUT AND SHAFT MINING.

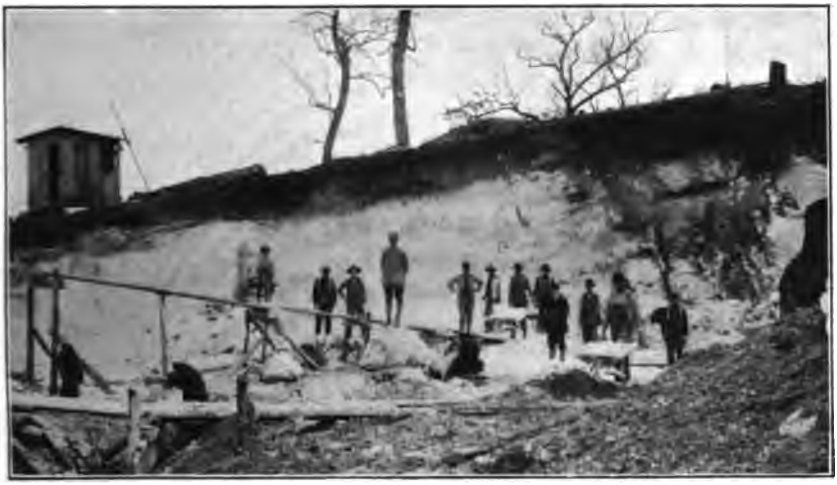
Many dikes are too narrow to justify mining by open-cut. Moreover, the necessity of removing the overburden by an uphill or very long haul, as well as special conditions, may make mining exclusively by open-cut unpractical. The manner of mining must be determined for each deposit, regard being given existing conditions. Even though the entire dike can not with economy be mined by open-cut, the upper portion for a depth of 30 to 40 feet may be mined by open-cut with far less expense than by shaft. When an open-cut is not more than 30 feet deep, sloping the walls is not expensive, and the overburden and waste removed will generally suffice to fill the shafts sunk into the lower portions of the dike. The practice is to remove overburden before shaft sinking only when the material removed can be utilized for filling a shaft from which all valuable material has been mined.

Working the upper part of a deposit by open-cut also reduces the cost of shafting because it exposes the dike and shows its width, thus insuring the shaft being sunk at the most advantageous point. (See *A* and *B*, Pl. XI, and Pl. XII.)

REMOVAL OF WATER FROM KAOLIN MINES.

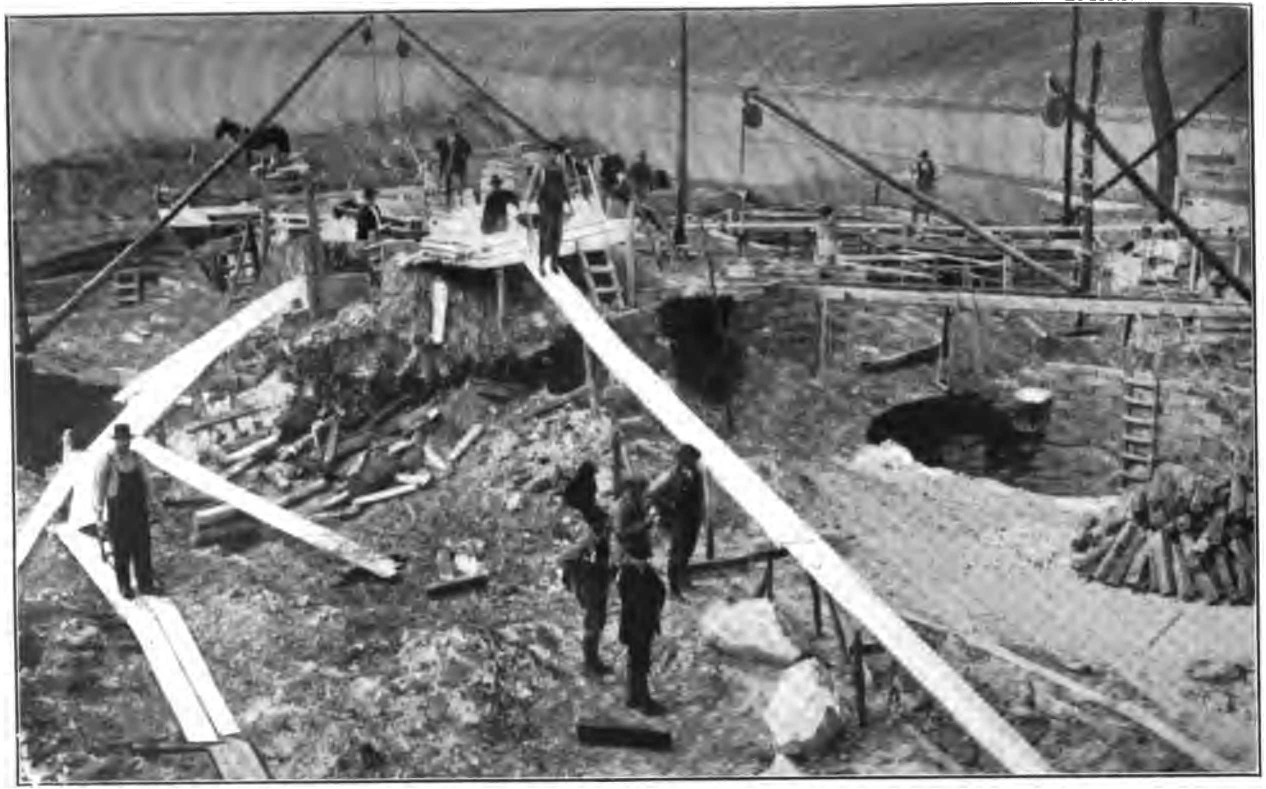
One of the most expensive items that the miner of kaolin in this region has to consider is the removal of water from the workings. The dikes are generally free from water to a depth of about 40 feet, but below this depth the seepage of water from the walls and from the dike itself often increases to an actual flow, and in many cases the inrush of water has driven the miners from the workings and stopped mining. In the earlier operations for mica it was customary to sink shafts to as near the water level as was considered safe, and drift along this level until a flow of water was encountered, then the shaft was abandoned and a new one sunk at no great distance. The mica found in the vicinity of the water is claimed to be especially free from faults and of the finest color.

In kaolin mining the same in general is true. The finest quality of kaolin is generally found in the area between the level at which the first water is encountered and the level at which the flow becomes a menace to mining. Within the region studied the refilling of shafts on account of an excessive flow of water has resulted in leaving behind enormous amounts of kaolin of the highest grade. The remining of this abandoned material can be accomplished only at great expense, since the shafts are filled with refuse which must be removed before the abandoned material can be reached. The cost of such an operation would be prohibitive.



A. OPEN-CUT MINING FOR KAOLIN, SHOWING IRREGULAR SURFACE OF DEPOSIT.

B. TYPICAL GRAVITY TRAMWAY.



SHAFT MINING AFTER THE OPEN-CUTTING.

Only the simplest methods have been used to remove water from kaolin mines, the uniform practice being to bail the water into barrels and hoist it to the surface. This practice requires no great outlay for special machinery, but delays the other mining operations and thus reduces the daily output of the shaft, which results in increasing the cost per ton of material produced. Moreover, the seepage of water into the shaft from all directions loosens the ground and increases its tendency to cave and slip.

The use of pumps for handling water has met with little success because the deposits contain much exceedingly fine sand which is carried in suspension by the water and cuts out the valves of pumps very rapidly. The height to which the water must be elevated varies from 50 to 120 feet, which precludes the employment of suction pumps or steam siphons. The running of tunnels at or below the level where water is encountered is the natural method of draining workings, but it has been tried at only one mine in the district and there was only a partial success, because although the deposit covered many acres of land the drainage tunnel was run into the deposit at only one point and no branch tunnels were run to assist in draining the more distant parts of the deposit. The tunnel, however, removed the greater proportion of the water, so that by occasional bailing mining could be carried on without great annoyance. At a mine in a similar dike outside this region the dike has been cut by numerous tunnels, all of which drain to a central sump or cistern, and the water is removed by pumps provided with filters for excluding sand. The mine is thus kept dry and mining is greatly facilitated.

The situation of a majority of these dikes is ideal for drainage from below. Most of them lie well above the present water courses and most of the hills slope so abruptly that few tunnels would have to be driven more than 100 yards before reaching dike material. After reaching the dike, the cost of running the drainage tunnel would be little, if any, more than the cost of mining the kaolin in other parts of the dike. To insure the maintenance of an open drainage way timbering would be advisable. The tunnel should be continued well into the dike and a number of branch tunnels should be run to the extreme limits of the deposit. The capacity some deposits have for holding water indicates that the complete drainage of a dike by tunnels can not be accomplished in a few days, but a number of weeks or even months may be required. The cutting of the drainage tunnel should therefore be started as soon as possible after the trend and general extent of the deposit are determined. When such a tunnel is run below the level at which kaolinization is complete, it may be advisable to place a shot of dynamite in the ends of each crosscut tunnel and thus rupture the formation, permitting the water more easily to drain away.

CONVEYING THE CRUDE KAOLIN TO THE WASHING PLANT.

The method of conveying the crude kaolin to the washing plant is of necessity influenced by the situation of the mines and the washing plant. At every mine except one studied in this region the mouth of the shaft or the floor of the open-cut is well above the washing plant.

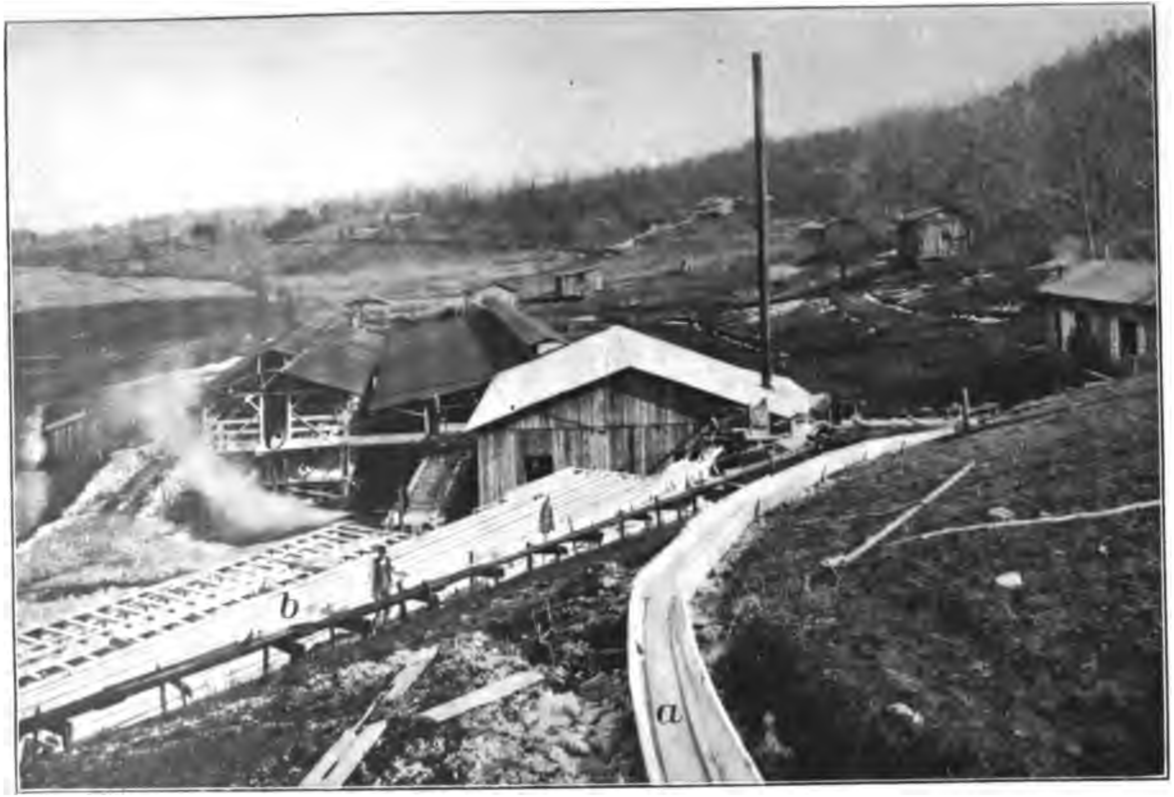
The method generally used is by flume, a stream of water being diverted into a V or U shaped trough (see Pl. XIII), into which the crude kaolin is shoveled. In most cases the flume is carried into the mine, so that the crude kaolin on removal from the shaft or bench may be shoveled directly into the flume and a second handling is unnecessary. In some cases, however, the flume is carried only to a point below the mine and the crude kaolin must be conveyed from the mine to the head of the flume. For this purpose a tramcar system has been used at two mines and is reported satisfactory. At one mine the tramcar system is supplemented by a gravity incline with cars. (See *B*, Pl. XI.)

In constructing a flume for transporting crude kaolin, caution must be exercised to avoid no abrupt turns and drops in order to prevent the small blocks of mica, which exist everywhere in kaolinized dikes, from being broken into thin sheets and flakes by the battering they would receive. If the small blocks of mica are not broken they are readily removed with the coarse material by the sand wheels. The chief advantages of transportation by flume are that it is economical and coarse lumps of kaolin are disintegrated before they reach the washer. (See Pl. XIII.)

REFINING THE KAOLIN.

CLAY WASHERS.

The first step in refining the crude kaolin is accomplished by the washer. This is really a disintegrator, since its chief service is so to agitate the kaolin-bearing material that the kaolin may be separated from the quartz and other waste materials. A washer, shown in figure 10, consists of a rectangular box measuring approximately 3 by 3 by 10 feet. Lengthwise through this box passes a shaft to which are attached a number of arms that extend almost to the sides of the tank. The shaft is belt driven by a pulley attached at the intake end of the washer and revolves at about 200 revolutions per minute. Washers are generally operated in batteries of two, the material to be disintegrated passing directly out of one into the other.



PLANT FOR WASHING KAOLIN. *a*, FLUME; *b*, MICA TROUGHS; *c*, DRYING SHED.

SAND WHEELS.

From the washers the crude kaolin passes to the sand wheels. Each wheel revolves in a narrow tank about 10 feet long and 6 feet high. To the spokes of the wheel are attached cast-iron scoops each having a sloping end. As the wheel revolves, charges of coarse material not disintegrated by the washer are scooped up from the bottom of the tank. Figure 11 shows perspective of sand wheel and appurtenances. The kaolin mixed with this waste material drains away as a scoop rises and when the scoop reaches the highest point of its circuit the coarse material slides out, is diverted by the sloping end in the scoop, and falls outside the tank. The kaolin and any other very fine material pass directly through the sand wheel and into the sand trough. In the Southern Appalachian region two sand wheels are generally used with two washers and at many plants they are arranged in two sets, the crude kaolin passing through a washer to a sand wheel and thence through another washer and through another sand wheel into the sand trough. In *A*, Plate XIV, streams of water are shown impinging upon the scoops as they are elevated, which loosen the material packed against the walls. The number of washers and sand wheels necessary to separate all the kaolin from the material mined can be determined only by actual test.

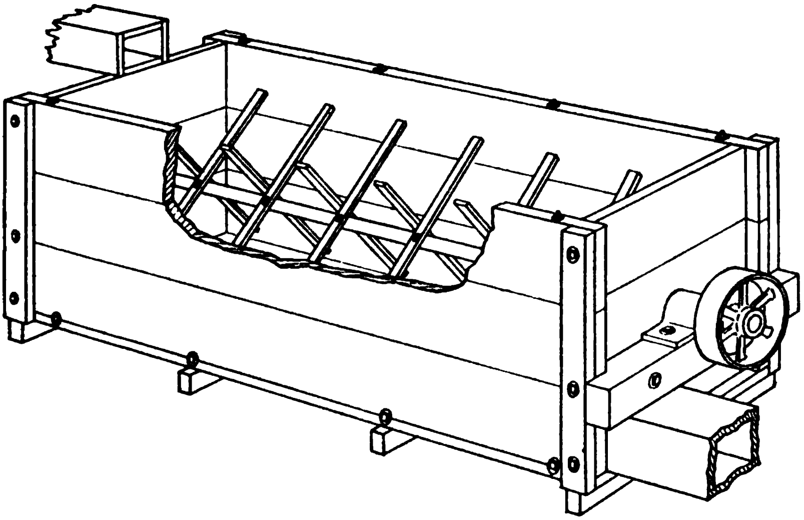


FIGURE 10.—Clay washer for kaolin.

The kaolin comes from the sand wheels thoroughly stirred and at such a rate of speed that much coarse waste is carried in suspension. To prevent this waste passing into the mica troughs, the sand trough or sand box is introduced.

THE SAND TROUGH.

The sand trough is made in two different styles, the broad trough and the square tank.

The broad trough, about 2 feet wide and 20 to 30 feet long (see *B*, Pl. XIV), is placed absolutely level and the flow of the kaolin-bearing slip is retarded by its distribution and the length of the trough. A barrier 4 to 8 inches high placed at the outlet end of the trough assists in retarding the flow. The coarse sand and the bulk of the coarse mica that passed the sand wheel are thus removed by settling and the fine material passes to the mica troughs. A workman with a shovel is kept busy removing coarse material from the trough.

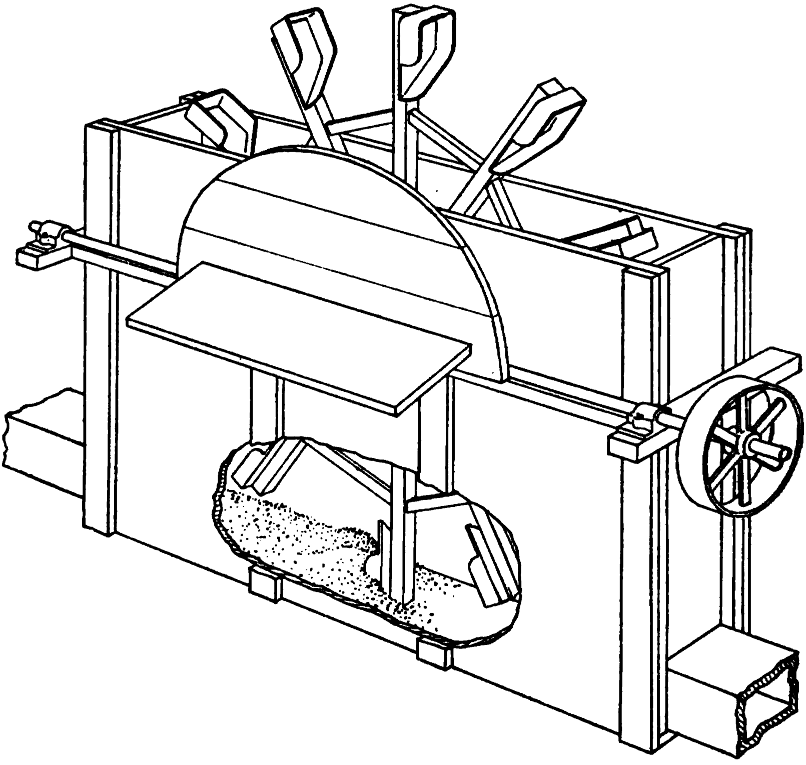
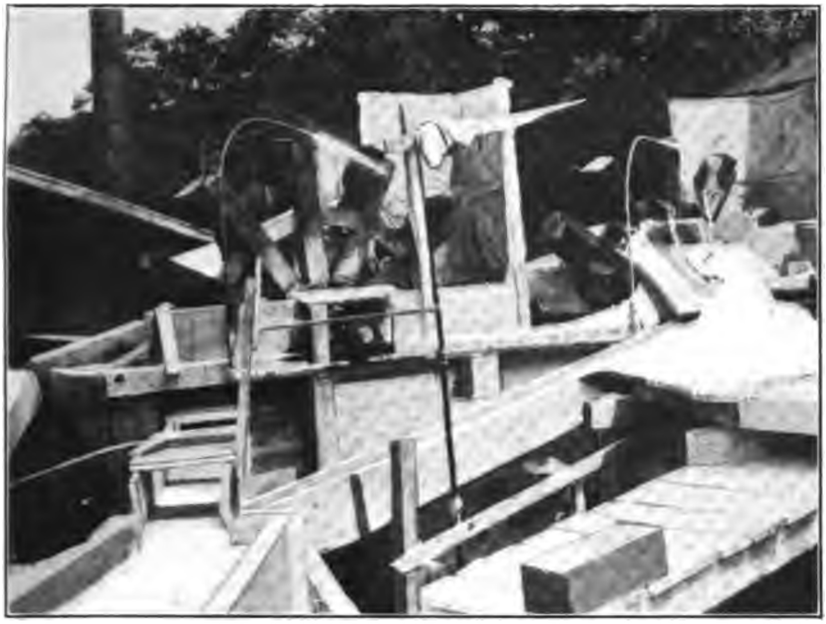


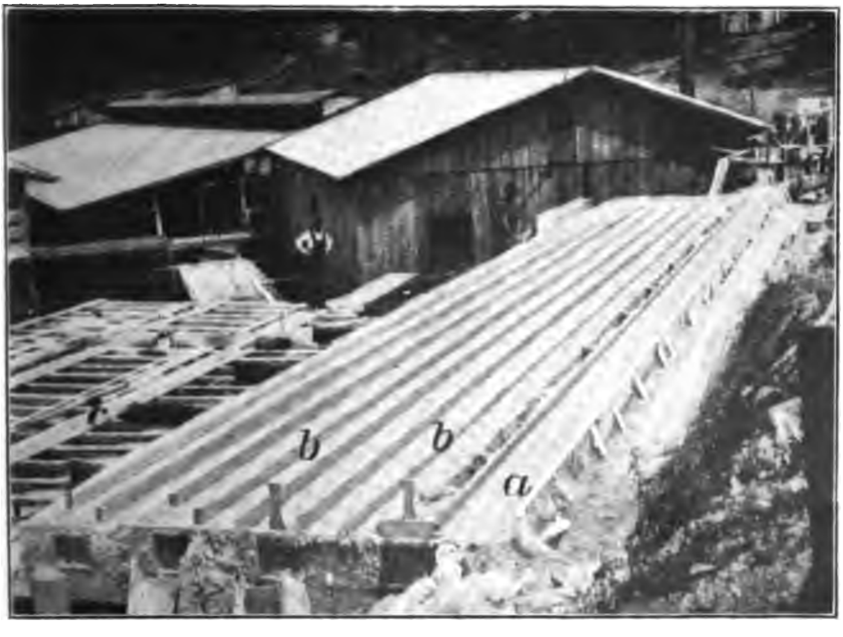
FIGURE 11.—Sand wheel in tank, broken away to show trough.

The construction of a sand box or square tank, if one is used instead of the sand trough, is as follows:

The fine material from the last sand wheel passes through a short trough into one end of a tank 6 feet long, 5 feet wide, and 1 foot deep. The outlet of this tank is 3 inches below the top and is placed either at right angles to the intake or at the same end of the tank as the intake. Thus the entering stream of kaolin-charged water expends



A. SAND WHEELS IN OPERATION.



B. TANKS AND TROUGHS AT A WASHING PLANT: *a*, SAND TROUGH; *b*, MICA TROUGHS; *c*, CONCENTRATING TANKS; *d*, SAND WHEEL.

its force in the volume of water in the tank and the material that does not settle in making the turn of 45 degrees or more floats off through the outlet into the mica troughs. (See *B*, Pl. XIV.) The material that settles is removed from the bottom of the tank with a scoop shovel.

THE MICA TROUGHS.

The mica troughs are the most important apparatus in a kaolin washing plant. They are constructed in several different designs, although their purpose is in every case the same—that is, the removal of the fine mica and sand.

The individual troughs are U-shaped and are generally 1 foot wide, 1 foot deep, and 40 to 50 feet long. They are built in batteries, the kaolin slip passing out of one tank into the next, back through that to its extreme end, and thence into the next trough of the battery. Much of the velocity of the kaolin-charged water is expended before the mica troughs are reached, and in order to keep the water moving the troughs are arranged in either of two ways: Each trough may have a drop of 1 inch from end to end, or each trough may be built absolutely level, with a drop of 1 inch between the troughs. In either case the fall is sufficient to maintain a flow. The number of troughs in the battery determines the grade of the product. By adjusting the slope of each trough or the drop between troughs, the grade of product may be regulated. The operation of the mica troughs is necessarily periodic, since to attempt to remove sediment during operation would result in floating off some material already settled and that the troughs are intended to eliminate. The usual way is to use the troughs for about 5 hours continuously, then discontinue the flow of crude kaolin and run clear water through the troughs for 15 to 20 minutes. Then the regular outlet from the troughs is closed and another outlet, which leads to the waste piles, is opened. By means of broad scrapers the sediment in the troughs is pushed out into the waste heap. Then the troughs are flushed clean with water and are ready for operation again. Cleaning takes about an hour and is done during the dinner hour and after the plant closes in the evening.

An arrangement of the mica troughs that is commonly used in washing clays in England, but is not employed in the United States, is to run the kaolin slips from the sand box into a broad basin from which mica troughs radiate in fan shape, each trough increasing in diameter toward the outer end and thus decreasing the flow. The method of operation and cleaning is the same as that described.

From the mica troughs the kaolin passes over a screen for removing any very thin flakes of mica that have floated through the troughs.

THE SCREEN.

There are three general types of screens—stationary, vibrating or sliding, and revolving.

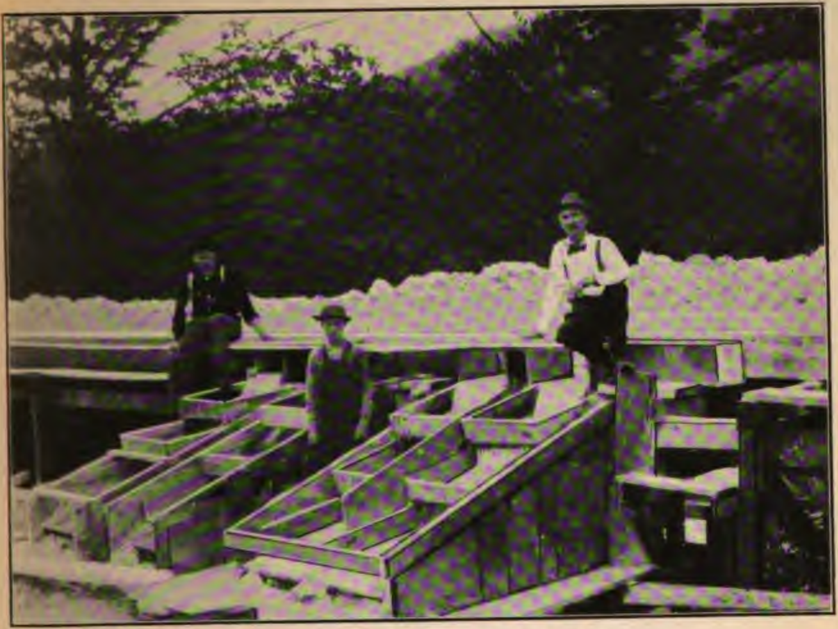
The stationary screen is most commonly employed in the region studied. (See *A*, Pl. XV.) The screens are arranged in batteries, each screen sloping about 10 degrees and discharging onto a similar screen placed about 6 inches lower. The excess material from the second screen overflows onto a third, and so on. Three screens are generally most efficient in a battery; if necessary, the kaolin slip is divided and a double, or a larger, battery is put in. The screens are simply built, consisting of box frames about 4 inches high, with brass wire attached to the bottom. An opening 2 inches wide across the lower end of a screen permits the excess material to flow onto the next screen. From the bottom screen the waste falls into a trough which may be emptied when convenient. These screens are all above a concrete or wooden basin, from which the material that passes through the screens runs into concentrating tanks.

The vibrating or sliding screen is suspended above a basin and shaken or slid rapidly back and forth by means of an eccentric or similar device, so that the coarse material is kept moving toward one end of the screen while the fine material and liquid passes through into the basin. The worst fault of this type of screen is that its rapid vibration tends to tear the mica flakes into pieces, which pass through the screen with the washed kaolin.

The revolving screen is a nearly horizontal revolving cylinder, covered with fine screen. Into one end the kaolin slip is run. As the cylinder revolves the slip passes many times around its circumference, the fine kaolin passing through the mesh, while the coarse material gradually works toward the outlet. By adjusting the slope of the cylinder the number of revolutions is regulated through which the material must pass before reaching the outlet. A spray of water from above washes loose any material adhering to the screen and materially increases the capacity. Such a screen requires little power and has been found very efficient. The material that passes through runs into a concentrating tank.

CONCENTRATING TANK.

The concentrating tank is merely a reservoir or a series of reservoirs (see *B*, Pl. XV) in which the kaolin slip stands until it has settled sufficiently to permit drawing off the excess water. Settling is very slow in some cases, and to hasten settling it is customary throughout the region to introduce a flocculator, in the form of alum, into the slip as it passes into the concentrating tanks. The alum in lump form is placed in a muslin bag suspended in the trough leading



A. BATTERY OF STATIONARY KAOLIN SCREENS.

B. END VIEW OF KAOLIN-CONCENTRATING TANKS.

from the screen. After settling, the excess water is siphoned off and the thick kaolin slip is run into an agitator.

AGITATOR.

The agitator, which is shown in figure 12, is a large cylindrical tank, in the center of which is a shaft with radiating paddles. The paddles stir the kaolin slip into a homogeneous mixture, and in this condition it is pumped from the agitator into the presses.

PUMP.

The pump used for filling the presses is a simple piston or plunger pump, driven by belt or occasionally by steam direct. The valve and valve seats have to be made of material that will resist abrasion. Valves of rubber and valve seats of bronze are commonly used. An overflow is provided in order that the rate of pumping may be kept at the maximum and the time for filling the presses be reduced to the minimum.

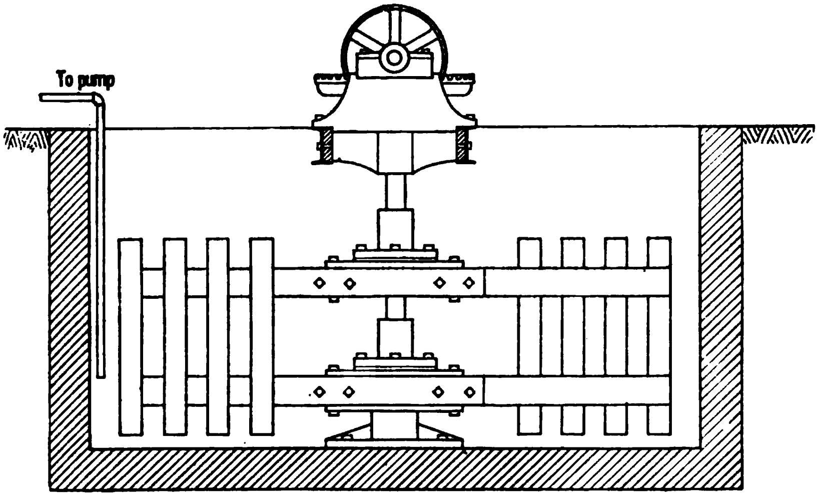


FIGURE 12.—Agitator used in refining kaolin.

PRESSES.

The presses were formerly made of wooden plates 30 inches square and 2 to 3 inches thick, hollowed out on each side for a depth of one-half to three-fourths inch. Canvas was stretched over the surfaces and the plates were set in batteries of 50 to 75. To introduce the slip into the openings between the plates, a groove was made through the rim of each plate on the top side, so that when two plates were placed together the opening left was just sufficient to receive a small iron pipe. To allow the water to pass out after being forced through the canvas, a series of small holes was bored through the rim along the lower edge of the plate and in the face of each plate grooves were cut leading to these outlets. The pressure on these wooden presses never exceeded a few pounds and the removal of water from kaolin slip by their use was very slow.

All of the plants now operating in the region investigated use a filter press having a heavy cast-iron and steel frame and heavy cast-iron plates. (See *A*, Pl. XVI.) The kaolin slip is introduced through an opening in the center of the plates and the canvas covering is sewed securely about these openings. The outlets for water are the same as in the old wooden presses, but are more numerous. With the presses now used the kaolin slip may be introduced at much higher pressure, and in most cases a pressure of 100 to 120 pounds per square inch is maintained in finishing the filling of a press. After the press is filled with solid kaolin the pump is stopped, the screw that holds the press plates together is withdrawn, and the cakes of pressed kaolin are removed. The cakes are not absolutely dry, but contain from 8 to 20 per cent water, hence additional drying is necessary before the kaolin is ready for shipment.

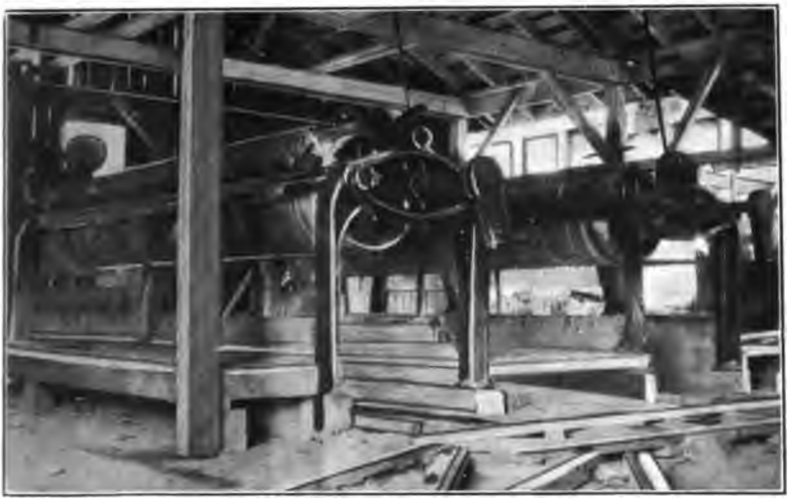
DRIERS.

The final drying of kaolin is accomplished by three different devices: Open-air driers, steam driers, and tunnel driers.

An open-air drier consists merely of a building containing racks on which the kaolin cakes may be exposed to the air and the moisture gradually evaporated.

A steam drier consists of an open building, on the floor of which are placed steam pipes connected at one end with heaters. (See *B*, Pl. XVI.) The damp kaolin is dumped directly upon these pipes, where it dries. When dry, the kaolin is shoveled off the pipes and is loaded directly into cars or wagons for shipment.

The tunnel drier is a device borrowed from modern brick making. On removal from the filter press the cakes of damp kaolin are loaded upon rack cars, which hold about 1 ton each. These cars are run into the drier, which is so constructed that the cars run by gravity toward the outlet. As a car of damp kaolin enters the drier a car of kaolin that has been dried is taken from the opposite end. The method of heating the air for this type of drier varies. The system used in this region is to force the air by fan through steam coils and into the drier.



A. ELEVATED FILTER PRESSES.

B. STEAM DRYER, SHOWING CAR TRACK IN CENTER AND KAOLIN ON THE STEAM PIPES, WHICH ARE LAID DIRECTLY ON THE FLOOR.

FAILURES IN KAOLIN MINING IN THE REGION INVESTIGATED; CAUSES AND REMEDIES.

INSUFFICIENT PROSPECTING.

The failure of the majority of kaolin-mining plants erected in the southern Appalachian region is due chiefly to insufficient or improper prospecting before the establishment of the plant.

The exposure of a small quantity of high-grade kaolin has resulted in the erection of a plant before the extent of the deposit was definitely determined. After the deposit has proved small or of inferior quality, and in case no other deposit in the district could be efficiently handled by the washing plant owing to its location, the plant is closed and perhaps dismantled, but stands as a warning to future prospectors for kaolin.

Had a thorough investigation of the deposit shown kaolin in commercial quantities, and had the prospects of kaolin from neighboring deposits been ascertained, the plant could have been so placed that its success as an investment would have been assured.

INEFFICIENT MINING METHODS.

Another cause of failure in many kaolin-mining enterprises throughout this district is the inefficiency of the mining methods employed. The removal of overburden by shafts instead of by open-cuts, the sinking of shafts where bands of quartz are known to exist and must be cut, inability to cope with water in shafts, and the necessary abandoning of much valuable kaolin on this account, are all causes which, combined, have resulted in many failures. Failure to cope with such difficulties can be charged only to poor engineering, since many mines have successfully operated under exactly similar conditions.

OPERATING BELOW CAPACITY OF PLANT.

A third cause of failure throughout the region is the common practice of operating at less than maximum capacity. In a majority of the ventures that failed the mines did not produce sufficient material to operate the washing plant to its capacity and no strenuous effort was made to increase their output. Consequently the operation of the washing plant and many other fixed charges had to be prorated against a reduced production, which changed the balance from profit to loss. Some of these poorly balanced operations have been due to the deposit proving smaller than at first supposed, but in such an event only one course is open to the operator—the deposit must be worked to the maximum capacity of the equipment and when it is exhausted other deposits must be sought.

The difficulties confronting the operator of large kaolin deposits are thus shown to be not inherent obstacles but rather the result of poor engineering practice.

WASTEFUL PRACTICES IN REFINING THE KAOLIN.

Several wasteful practices in refining kaolin are prevalent throughout this district. The worst are discussed below.

CRUSHING AND PULVERIZING MICA IN CRUDE KAOLIN.

The common practice of dumping all small blocks of mica into the flume, where they are battered about on the journey to the washing plant, results in mixing with the kaolin much fine mica that is removed with difficulty; in many cases this mica is not removed but lowers the grade of the kaolin produced.

LACK OF BLENDING FACILITIES.

The common practice of rushing the kaolin from the mine to the washing plant provides for no blending of material from the various parts of the workings before washing. The small settling tanks and concentrating tanks provide little opportunity for blending large quantities of material. The natural result is a variation in physical properties of shipments from the same deposits, and this discourages confidence in the material produced.

VARIATION OF SLIP DENSITY IN THE SAND AND MICA TROUGHS.

The irregularity with which material is fed into the washing apparatus results in a variation in the density of the slip. When the kaolin slip is dense it may carry a large amount of sand and mica beyond the mica troughs and into the settling tanks. When the slip is thin, all sand and mica quickly settle out in the troughs and only the finest kaolin reaches the settling tanks. Thus the regulation of the crude material fed into the washing plant is an important point if a uniform product is desired.

OPERATION OF SMALL DEPOSITS.

The development of the kaolin industry in this region is dependent upon the utilization of the kaolin from the small dikes, those that are worked at present for mica only and from which the kaolin is wasted. Several of these deposits if worked with due regard for kaolin as well as mica would produce almost as much kaolin as some operating kaolin plants, but in the majority of cases the output would be from 1 to 5 tons per day.

CENTRAL KAOLIN-WASHING PLANT.

The handling of this quantity of material would not justify the erection of a power-operated washing plant in most instances, but where several extensive mica mines are producing kaolin as a waste product, a commercial kaolin-washing plant of moderate size could doubtless be operated with profit, the crude kaolin being bought at a price based on its kaolin content. A thorough blending system would be necessary in order to insure a uniform product, and ample storage would be required to carry reserve stock in order to make blending possible. The uncertainties of kaolin mining would be eliminated from such a venture, and since the costs of operating the necessary plant are easily determined, the enterprise should make a safe investment. However, the utilization of kaolin by a central washing plant is only practical when the plant is within a few miles of the source of supply; otherwise the expense of hauling the enormous amount of associated dike material to the washing plant would make the venture unprofitable.

Where the kaolin supply is scattered over a large area and operations can not be conveniently centralized, the only plan available is to concentrate the kaolin and sell it, either as washed kaolin or as concentrated crude kaolin.

Where time is not an important consideration, the washing of kaolin may be successfully accomplished without the use of any machinery and a product equal to the best machine-washed kaolin produced.

HAND WASHING KAOLIN.

Hand washing of kaolin is copied in part from similar operations in Cornwall, England, and has been altered to suit the conditions in the region investigated. The crude material is placed in a shallow level tank measuring approximately 4 by 20 feet. Water is admitted at one end and passes out at the other, the material meanwhile being vigorously stirred with shovels to loosen the hard kaolin which adheres. The water from the tank enters a sand-settling trough measuring approximately 2 by 50 feet by 1 foot deep. In passing this the coarse sand settles and the fine material passes out at the opposite end, which is partly closed by a gate 8 or 10 inches high. The material that settles must be stirred occasionally to liberate any kaolin caught in it. From the sand trough the kaolin slip passes into the mica troughs, which are similar to those used in all kaolin-washing plants and are approximately 1 foot wide and in 50-foot sections, either eight or ten sections being used. The depth of slip in these troughs is regulated by the flow of water, as ordinarily they contain no retarding strips. These troughs are built in batteries side by side.

The slip flows from one trough to the next, back and forth, and at the end flows onto a series of screens which are so built that the overflow from the first screen passes onto the second and then onto the third.

The size of screen must be selected especially for the work in hand. Some crude kaolins can be cleaned of the last traces of floating mica by the use of the 100-mesh screen, whereas others require the 120-mesh screen or even 150-mesh screen to remove the finest mica. The mesh stated is the number of meshes per linear inch.

Thus a great proportion of the mica not settled in the troughs is removed and the refined kaolin passes into the concentrating tanks, which should be approximately 30 by 10 feet by 6 to 8 feet deep. There should be two, so that slip may be introduced into one tank while the other is in use. When a tank is filled the slip should be allowed to stand until the kaolin has settled completely to a thick paste and the clear water can be siphoned off. After removal of the water, the kaolin paste is transferred to shallow evaporating tanks, approximately 30 by 10 feet, and not more than 2 feet deep. Here the material may remain until any desired degree of drying has been reached. Much time will be saved, however, if the material is removed as soon as it will hold together and exposed upon open-air drying racks. In the Cornwall district the material when dry enough to move with a shovel is transferred to the top of a tile-covered oven approximately 100 by 5 feet in area and consisting of two long flues. Here the last traces of water are removed. The material after drying is marketable kaolin.

Material that has been once washed for kaolin may be wisely removed from the washing tank and, after air-drying, may be rewashed, often to produce considerable marketable kaolin.

PRECAUTIONS FOR THE HEALTH AND SAFETY OF WORKMEN.

Labor conditions throughout the southern Appalachian region are satisfactory, the demand for workmen being supplied by native laborers. Most of the small mines are operated for mica only and the workmen work on a percentage basis and thus assume their own risk. The precautions for the safety of the workmen thus employed are few, but long acquaintance with this kind of work enables the miner to judge the condition of walls and roof, and therefore accidents in small mines in this district are rare. In mica mines the entering shaft is generally cribbed, but beyond this no timbering is done except where a mass of roof cracks or a wall shows unmistakable signs of giving way. Mining methods in most of the small mines have improved very slowly. Black powder for blasting has been replaced by 40 per cent dynamite in most mines and fuse has been replaced by electric detonators in some places. No artificial ventilation of mines is used in this district and in few instances is it required. Where "ground-hog" mining methods are practiced, the difficulty of removing even the small amount of dike material which must be taken to the surface makes it economical to open new surface connections at short intervals. Hence a number of outlets to most mines are provided and ventilation is assured.

The most dangerous practice in connection with small mining operations in this district is the building of lofts in stoping. These lofts are constructed of small hewn timbers and are loaded to the crushing point with refuse material. The miner is often required to pass under such lofts daily or hourly and during blasting the danger of these old lofts collapsing becomes very great, as the timbers are rotten from the damp atmosphere of the mine.

In mining kaolin by shafts timbering is carefully done and there is little or no danger from the collapse of timbering.

The robbing of the dikes in the neighborhood of the shafts is effected by means of short tunnels which are seldom timbered, as the danger from caving is very small. The tunnels rarely reach 10 feet in length and are about 4 feet wide, hence the miner would have little difficulty in escaping in case the roof or walls collapsed. The material in these short tunnels rarely caves, no doubt because the robbing of the dike is never attempted until the full depth to which the dike is workable has been reached. Thus the surrounding dike material has ample opportunity to drain before being disturbed.

A precaution that is generally neglected throughout this district is the erection of substantial guard rails about the mouths of open shafts. It is necessary in the removal of material for several men to work constantly about the mouths of the shafts, often leaning over the open shafts, and a misstep is almost certain to result in a man falling in. No barrier is provided about the mouth of the open shafts to prevent refuse material rolling in and falling upon the workmen below. After the shaft is sunk to the maximum depth and the robbing of the dike begins, the workmen, if warned of the falling of something into the shaft, may seek refuge in the short tunnels, but in shaft sinking no such escape is possible.

Each shaft is provided with a ladder from bottom to surface for the use of workmen who do not wish to enter and leave the shaft by means of the buckets. The ladders, although seldom used, are generally kept in good repair. The buckets are made of barrels strongly banded with steel hoops and additionally reinforced with bands of iron passing completely under the bottom. The hoisting cable in the larger operations is $\frac{5}{8}$-inch or $\frac{3}{4}$-inch steel cable, and the maximum capacity of the buckets is about 600 pounds. Where the buckets are operated by hand windlasses hemp cable is used for hoisting, and this is never less than $\frac{7}{8}$ inch in diameter. The load lifted is never more than 400 pounds. The cables used are carefully inspected by the operators at frequent intervals, as they fully realize the damage that would result from the breaking of a cable with the workmen directly below.

The general health of workmen in the region is excellent, and although they are much exposed to the weather when operations are continued throughout the winter months, little sickness is reported. The health of workmen employed about kaolin-washing plants is fully up to the average. No injurious results are to be expected from such labor and none is reported. Workmen employed in the handling of kaolin that has been artificially dried are forced to work in a somewhat dusty atmosphere, but no case of injury to health has been recorded, although workmen have been continuously employed in this work for many years.

POOR ROADS.

One of the greatest hindrances to the development of the mining industry of this region is the poor roads. Throughout the district between the Blue Ridge and the Great Smoky Mountains few improved roads exist. Within the past five years an effort has been made to reduce the grade on many of the roads and thus lessen the excessive washing each winter. This washing ruins every road with a steep grade, and each spring a great amount of grading must be done before the roads are fit for hauling. Road building in many sections is nothing more than "brushing," which consists of filling the gulleys with brush and covering the brush with soil. The brush prevents washing to some extent, but the water collects in the soft soil to make miry places. The soil consists principally of weathered gneiss carrying much chlorite and other micaceous material, which is a poor road foundation, and until the building of roads is undertaken in a more substantial manner the hauling of material for a great distance will be difficult, if not impossible. In some districts granitic material is available and the pegmatite material from the dikes has been used to a limited extent, but the use of these materials is very limited except in the vicinity of some of the larger towns. The best roads in this district are the creek beds, which in many places furnish a solid, although rough road, always passable except in time of freshet. During a short period in winter, when the ground is frozen, hauling can be done with reasonable economy over all roads.

The summer season during which hauling is possible lasts about six months, from May to November, varying from year to year.

The transport of the dike materials except by railroad must therefore be more or less periodic, depending upon the weather and season. This fact is considered in hauling lumber throughout this region, and the work is so arranged that no great inconvenience results. The same plan could be followed by kaolin miners, and storage might be provided at the plant and railroad so that operations could be continued during the seasons when roads are blocked.

The difficulty of haulage may at many mines be overcome by careful selection of the site for the washing plant so that the washed kaolin may be floated a large part of the distance to the railroad, there pressed and dried, and then by a short haul delivered to the shipping point.

MICA AS A BY-PRODUCT OF KAOLIN MINING.

At many pegmatite dikes that have been worked for kaolin no attempt has been made to save any mica found except such as promises to cut first-class sheet mica or at least high-grade electric mica.

Large amounts of mica that is not sound have been either thrown on the dump or allowed to remain in the crude kaolin to be pulverized, and thus increase the proportion of the most injurious constituent in the washed kaolin.

Solid crystals of mica that are too small to promise sheet material, but are solid and would produce first-grade small "punch mica," have been wasted in many places where kaolin has been mined, and are now buried under other refuse material, which makes later recovery practically impossible. Such mica varies in size from 1 inch to 2½ inches in diameter, and blocks weighing one-fourth to 1 pound are frequently noted in the dumps about the kaolin mines, particularly in the refuse from the sand wheels. The collecting of this material has never been attempted by mechanical means, but its removal by hand sorting would be perfectly feasible if the refuse from the sand wheels were conveyed by a broad picking belt to the dump. Such solid mica is always marketable for "punch mica"; from it small disks are "punched," or cut by die, and are used as insulators in electrical appliances. The mica that is not solid is useful only for "grinding mica," and of this the supply in recent years does not equal the demand.

In addition to this coarse mica, a large amount of fine mica, partly broken from larger blocks and partly in the form of small crystals, is carried past the sand wheels and collects in the sand-settling trough or tank. The amount obtained by experiments in Macon County, North Carolina, would indicate that a screen of coarse mesh introduced either at the inlet or outlet of the sand-settling trough would yield a good quantity of mica of small size which, by washing, could be freed from sand and made suitable for grinding mica.

In most plants for washing kaolin in this region the screens at the outlet of the mica-settling troughs yield little else but mica mixed with a small amount of kaolin. The rewashing of this material removes the fine kaolin, and the mica may, by a small amount of grinding, be prepared for market.

Nearly all marketed kaolins from this district contain fine mica. This could be removed to a great extent by the use of finer screens and a thinner slip in washing. The mica that would thus be recovered has been estimated to be worth more than twice that of an equal amount of the kaolin in which it forms an impurity.

The size of this waste mica varies in different portions of this district, as does also the color, although the luster seems to be uniformly good.

The territory west of Cowee Mountain in Macon County and the Tuckasegee River district of Jackson County yield chiefly coarse mica, except where pulverized by the washing process. The fine mica recovered in these territories is in the refuse from the sand wheels and in the sand troughs.

In Swain County, North Carolina, the white pegmatites yield a considerable amount of fine mica in the sand troughs and a small amount in the mica troughs and screens, although this district is not rich in fine white mica.

The expanded lenses of the territory about Sprucepine, Mitchell County, N. C., are chiefly productive of mica finer than the size removed by sand wheels. The sand-settling tank, the mica troughs, the screen refuse, and even the washed kaolin itself contain much mica of small size, and the color of this mica is very good, being green mica in many cases and of high luster. The narrow, more sharply defined dikes in this neighborhood do not yield much small mica. Fine mica of good quality was also noted in deposits in Buncombe County, North Carolina, and in Pickens County, Georgia, at the southwest extreme of the region investigated.

GRINDING MICA FOR WALL PAPER, ELECTRICAL INSULATION, AND LUBRICATION.

Although a large amount of sheet mica for use in stove fronts and for electrical purposes is shipped each year from this district, an enormous amount of mica is mined annually that is not solid and is valuable only as grinding mica.

The method of grinding mica is unique, since the process is shredding rather than abrasion. The process in detail is as follows: The coarse mica is washed by passing it through a revolving cylindrical screen upon which water plays and thus any fine sand is washed away. The washed mica scrap collects in a tank of water and any refuse that floats is carried off by the water, which constantly overflows the tank.

The mica-grinding mill into which the mica next goes is a cylindrical wooden vat 3 feet high and approximately 3 feet in diameter with a wall 6 to 8 inches thick, built of wooden blocks set with the end of the grain toward the inside to present a wearing surface. The grinder is a wooden wheel about 6 inches thick that fits loosely inside the vat. This wheel is built of ordinary plank cut to present as much end grain as possible and spiked together to give the desired thickness. It is attached to a heavy vertical shaft in the center of the vat and is rapidly revolved by steam or water power. The pressure of the wheel on the material in the vat is maintained by a pressure spring from above.

The operation consists of charging the mill with washed scrap mica and adding just enough water to provide the desired lubrication. The wheel is then started and pressed down until it takes a firm hold upon the mica. The friction of the wheel against the mica scrap causes the sheets of mica to be forced between the laminæ of adjoining sheets and thus the large blocks and sheets are gradually torn to pieces and reduced to the pulverized mica of commerce. After 8 to 10 hours the mill is emptied, and by a flotation system similar to that used for removing mica from kaolin the fine mica is separated. The coarse mica is returned to the mill and the fine mica is allowed to settle and the water drawn off. The mica is then removed to drying tables where it is spread to dry. After drying it is placed in regular bolting machines similar to those used for bolting flour; the last trace of coarse material is removed and returned to the grinding mill. One such grinding mill will produce from 250 to 400 pounds of 160-mesh mica per day, hence many mills are necessary for a large output.

When no water is used with the mica in grinding, the process is more rapid, but the product lacks the luster of the wet-ground mica and is marketable only for lubrication products and for use in electrical insulation.

The supply of mica for this industry has been obtained up to the present time from operating mica mines, with occasional supplies brought in from abandoned mica sheds where refuse material has accumulated.

The supply is, however, not equal to the demand, and each year is finding the operators of mica-grinding mills working farther into the mountains in search of material. The material that must be ultimately used, and which it is safe to predict will equal in quality the present material, is the refuse mica from the kaolin plants. This material constitutes in some places more than 15 per cent of the total deposit, and in washing the kaolin more than 65 per cent of the coarse material that passes the mica-settling troughs is pure white mica. Thus the process of obtaining this material must change soon from a search for coarse material for grinding to a utilization of the partly ground material already at hand and now being discarded as waste.

ANALYSES OF FELDSPAR, SEMIKAOLINIZED FELDSPAR, KAOLIN, OCHER, SCHROETTERITE, QUARTZ, AND WAD.

Analyses of feldspar, semikaolinized feldspar, kaolin, ocher, schroetterite, quartz, and wad are presented below. These analyses have been collected from various sources as the references indicate. Elements other than those mentioned were not sought by the analysts.

Analyses of feldspars.

Mine.	H_2O.	SiO_2.	Al_2O_3.	Fe_2O_3	TiO_2.	CaO.	MgO.	BaO.	Na_2O.	K_2O.	Total.
Witherspoon mica mine, Ashe County, N. C.[a]	0.90	64.48	19.43	0.01	Trace.	Trace.	Trace.	0.00	1.84	13.19	99.85
Avery Meadow mica mine, Avery County, N. C.[b c]	......	62.95	19.66	......	......	Trace.	......	......	7.64	8.39	......
Plumtree mica mine, Avery County, N. C.[a]	.17	65.37	17.92	.02	Trace.	.17	Trace.	.00	2.10	13.05	98.80
Lisle Knob mica mine, Macon County, N. C.[a]	.30	65.40	20.70	.10	Trace.	1.60	Trace.	.00	6.10	6.00	100.20
McGuire Prospect, Macon County, N. C.[a]	.60	63.90	19.97	.15	Trace.	.05	Trace.	.70	1.01	13.20	99.58
Southern Clay Co. mine, Macon County, N. C.[a]	.50	64.30	19.64	.08	Trace.	Trace.	Trace.	.17	1.32	14.00	100.01
Carolina Mineral Co. (Albite), Mitchell County, N. C.[a]	1.00	64.92	22.28	.21	Trace.	1.60	Trace.	.00	9.20	1.10	100.31
Carolina Mineral Co. (Microcline), Mitchell County, N. C.[a]	.30	65.68	19.08	.14	Trace.	Trace.	Trace.	.00	2.08	13.09	100.37
Cloudland mica mine, Mitchell County, N. C.[b c]	......	65.18	21.60	......	......	.64	......	......	8.35	.04	......
Cook mica mine, Mitchell County, N. C.[a]	.40	64.93	19.45	Trace	Trace.	.05	Trace.	.00	2.54	12.46	99.83
Flat Rock mica mine, Mitchell County, N. C.[b c]	......	65.15	19.04	......	......	.12	......	......	7.00	7.28	......
Wiseman mica mine, Mitchell County, N. C.[b c]	......	64.85	19.90	......	......	.00	......	......	10.04	2.91	......
Granite from Mitchell County, N. C.[a]	.90	75.10	15.57	.47	.03	1.10	Trace.	.00	2.86	3.49	99.52
Ray mica mine, Yancey County, N. C.[a]	.20	68.18	20.12	.05	Trace.	.85	.05	.00	9.38	.66	99.49
Do.[b c]	......	63.55	20.20	......	......	Trace.	......	......	6.65	8.73	......
McNichols Co. mine, Bedford County, Va.[a]	.10	68.75	18.56	.03	Trace.	1.25	Trace.	.00	4.29	6.85	99.83

[a] Analysis by Prof. D. J. Demorest, Ohio State University.
[b] Elements not mentioned were not sought.
[c] Analysis by the North Carolina Geological Survey.

Analyses of semikaolinized feldspars.

[D. J. Demorest, analyst.]

Mine.	H_2O.	SiO_2.	Al_2O_3.	Fe_2O_3	TiO_2.	CaO.	MgO.	BaO.	Na_2O.	K_2O.	Total.
Forest Hill mica mine, Jackson County, N. C	0.90	63.35	20.07	0.15	Trace.	0.03	Trace.	0.00	1.11	13.70	99.31
Moore mica mine, Macon County, N. C	2.05	63.74	20.90	.12	Trace.	Trace.	Trace.	1.10	.19	11.70	99.80
Southern Clay Co. mine, Macon County, N. C	1.40	62.47	21.00	.05	Trace.	Trace.	Trace.	.30	.90	13.62	99.74
Seth Freeman prospect, Madison County, N. C	5.42	65.05	22.39	.29	.12	Trace.	Trace.	.30	.21	6.53	100.31
Flukin Ridge mica mine, Mitchell County, N. C	1.34	63.32	20.45	.07	Trace.	Trace.	Trace.	.00	.80	14.20	100.18
Isinglass Hill mica mine, Rutherford County, N.C.	3.60	60.47	23.45	.10	Trace.	Trace.	Trace.	.00	.65	12.10	100.37
Harris Clay Co., Bryson City mine, Swain County, N. C	.94	63.60	20.40	.32	Trace.	Trace.	Trace.	.00	.50	14.40	100.16

Analyses of kaolins.

[D. J. Demorest, analyst.]

Mine.	H_2O.	SiO_2.	Al_2O_3.	Fe_2O_3	TiO_2.	CaO.	MgO.	BaO.	Na_2O.	K_2O.	Total.
Kinsland mine, Haywood County, N. C	11.90	50.64	35.57	0.25	0.03	Trace.	Trace.	0.07	0.08	1.70	100.24
Buchanan prospect, Jackson County, N. C	13.77	46.30	39.06	.20	.04	Trace.	Trace.	.00	.11	.60	100.08
Forest Hill mica mine, Jackson County, N. C	12.53	49.20	37.58	.17	Trace.	Trace.	Trace.	.00	.13	.47	100.08
Harris Clay Co., Dillsboro mine, Jackson County, N. C	13.99	46.95	37.73	.15	.05	Trace.	Trace.	.00	.18	.60	99.65
Piedmont Tin Mining Co., Lincoln County, N. C	12.00	48.50	37.35	.85	Trace.	Trace.	Trace.	.00	.32	1.02	100.04
Gurney Clay Co., Macon County, N. C	14.72	44.00	40.79	.11	Trace.	Trace.	Trace.	.00	.07	.55	100.24
McGuire prospect, Macon County, N. C	14.00	46.35	39.00	.30	Trace.	Trace.	Trace.	.00	.00	.50	100.15
Raby mica mine, Macon County, N. C	13.80	46.90	38.60	.25	Trace.	Trace.	Trace.	.00	.26	.39	100.20
J. J. Smith prospect, Macon County, N. C	12.55	48.05	37.69	.31	Trace.	Trace.	Trace.	.00	.02	.91	99.53
Southern Clay Co., Macon County, N. C	13.22	46.67	39.07	.11	.02	Trace.	Trace.	.00	.11	.25	99.45
West prospect, Macon County, N. C	12.70	48.92	36.37	.37	.02	Trace.	Trace.	.00	.11	.29	98.78
Harris Clay Co., Sprucepine mine, Mitchell County, N. C	14.80	45.20	38.45	.45	Trace.	Trace.	Trace.	.00	.00	.65	99.55
Tolley mica mine, Mitchell County, N. C	14.00	46.35	38.80	.25	Trace.	Trace.	Trace.	.03	.00	.41	99.84
Harris Clay Co., Bryson City mine, Swain County, N. C	14.10	46.95	37.24	.40	.05	Trace.	Trace.	.00	.24	.49	99.47
Elizabeth Smith mica mine, Yancey County, N. C	13.10	45.95	39.20	.05	Trace.	Trace.	Trace.	.03	Trace.	.50	98.83

Analyses of ocher, schroetterite, sugar quartz, and wad.[a]

[D. J. Demorest, analyst.]

Material and locality.	Loss on ignition.	SiO_2.	Al_2O_3.	Fe_2O_3.	TiO_2.	Na_2O.	K_2O.	Mn_3O_4.	CaO+ NiO.	CuO.
Ocher, Yonce prospect, Macon County, N. C	13.59	15.40	16.25	51.00	0.30	......	......	......	......	......
Schroetterite, Jackson County, N. C	28.10	21.90	49.60	.30	......	......	0.10	......	......	......
Sugar quartz, Macon County, N. C	.10	99.32	.49	Trace.	......	......	......	......	......	......
Wad, Macon County, N. C	15.30	33.20	24.60	4.00	.25	......	......	21.80	0.75	0.50

[a] Elements not mentioned were not sought.

FELDSPAR MINES AND PROSPECTS.

GEORGIA.

DALLAS. OLD TURNER MICA MINE. MICROCLINE.

This mine is 5 miles north of Dallas, Paulding County, Ga. The nearest shipping point is Dallas. The workings are one-fourth mile north of the farmhouse on two knolls. The openings are pits that have long since caved, making attempts at investigation unsatisfactory. Two bands of pegmatite are visible on one knoll, but both contain much coarse quartz and do not exceed 18 inches in diameter. A broad band of feldspar, reported to be present in these workings, could not be reached, owing to the condition of the pits.

Samples of the pegmatite taken from the exposed part of the dike show a deformation temperature ranging from 1,305° to 1,325° C., and fuse to a clear glass with a slightly yellow tint.

Properties in standard porcelain mixture.

In the mixture fired at 1,300° C. the feldspar shows vitrification, but at 1,350° no warpage. The color is the same as the standard trial. Fired at 1,350° in the mixture, this feldspar has a translucency of 0.62. The transmitted light is cream colored; the plastic molded shrinkage green to 1,350° C., 15.5 per cent. Under the raw-lead and fritted glazes the color is unaltered.

JASPER. DAVIS MICA MINE. MICROCLINE.

This mine is 4½ miles south of Jasper, Pickens County, Ga. The nearest shipping point is Jasper. It is an open pit, originally 6 by 8 by 8 feet deep. The caving of walls and washings from surrounding fields have practically refilled the pit so that there is little opportunity to study the formation. The pit is located in an open lot 25 feet above a small brook and is surrounded on all sides by much higher ground.

The mine is in a pegmatite dike about 4 feet wide, has a general north strike, and where exposed an almost vertical dip. No other exposure of this dike is found near by, and hence its industrial importance can not be determined. A kaolinized dike (see p. 118) of similar pegmatite, located one-fourth mile west of this deposit, has practically the same strike and dip.

The dike where exposed consists almost entirely of unaltered feldspar with intergrowths of quartz, giving a graphic structure. The feldspar is milk-white, free from any impurity except minute seams of silica, and a small amount of muscovite mica, which, however, is not much mixed with the feldspar.

The feldspar has a deformation temperature ranging from 1,305° to 1,325° C., and fuses to a clear bright glass.

Properties in standard porcelain mixture.

In the standard porcelain mixture fired at 1,300° C. the feldspar shows vitrification, but at 1,350° no warpage. Its color in the porcelain mixture is practically the same as the standard trial. Any difference in color is in favor of the feldspar. Fired at 1,350° in the mixture this feldspar shows a cream tint and a translucency of 0.65 and a total plastic shrinkage of 15.6 per cent. Under the raw-lead and fritted glazes the color is unaltered.

NORTH CAROLINA.

BAKERSVILLE. BUCKEYE MICA MINE.

This mine (91) is at the head of White Oak Creek, 5 miles southeast of Bakersville, Mitchell County, N. C. This dike is about 8 feet wide, and, near the surface, is almost pure feldspar, but the feldspar apparently forms a lens and pinches out at a depth of about 10 feet, below which is pegmatite. The dike strikes north and dips almost vertically. An inclined tunnel has been driven into this dike and its face is reported to be 40 feet below surface, but this tunnel is filled with water and there is no other way to ascertain whether the lower portions of the dike contain pure feldspar.

BAKERSVILLE. CLOUDLAND MICA MINE. ALBITE.

This mine (92) is on the north face of a spur of Yellow Mountain 400 feet above the Bakersville-Plumtree road, 1 mile south of the road and 5 miles east of Bakersville, Mitchell County, N. C. The nearest shipping point is Toecane, 2 miles west of Bakersville.

This pegmatite dike averages 14 to 16 feet in diameter, the mica running chiefly along the walls. It strikes N. 40° E. and dips 75° SE. Adjoining the walls are numerous bands of pegmatite very low in feldspar and carrying large amounts of garnet, tourmaline, beryl, biotite, mica, and other impurities. This dike has been opened for 120 yards and to a depth of 70 feet in places. The open-cut averages about 35 feet deep. The high-grade feldspar band in the middle of this dike averages about 4 feet thick and has the following chemical composition:

Composition of high-grade feldspar band.[a]

SiO_2	65.18
Al_2O_3	21.60
K_2O	.04
Na_2O	8.35
CaO	.64
	95.81

This feldspar has a deformation temperature ranging from 1,295° to 1,300° C., and produces a milk-white glass when fused.

Properties in standard porcelain mixture.

In this mixture the feldspar produces vitrification at 1,300° C., and at 1,350° shows slight warping. The color is equal to the standard trial. The translucency is 0.69 and the transmitted light is cream colored. The total shrinkage is 15.3 per cent in the mixture fired to 1,350°, 3 per cent drying shrinkage, and 12.3 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

BAKERSVILLE. LICK RIDGE MICA MINE.

This mine (85) is 2 miles northeast of Bakersville, Mitchell County, N. C., on Lick Ridge, a spur of Pumpkin Patch Mountain.

The dike is a mixture of feldspar and pegmatite. The feldspar band in the upper portion of the exposure is as much as 8 feet thick, but rapidly narrows and at a depth of about 10 feet practically pinches out, being replaced by pegmatite. The dike strikes north and is exposed about 60 feet. Since the depth of the exposure is only 10 feet, not enough material is exposed to justify an opinion as to the advisability of mining operations and therefore no sample was taken.

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[a] See North Carolina Geol. Surv., Economic Paper No. 6, p. 49.

BAKERSVILLE. J. T. WILSON MICA MINE.

This prospect (90) is 2 miles southeast of Bakersville, Mitchell County, N. C., on White Oak Creek.

The pegmatite dike is 15 to 18 feet wide and is exposed about 60 feet along the slope of a hill that runs to the northeast. The dike strikes N. 20° E. Along the walls there is mica, but the mica-bearing pegmatite is never more than 4 feet wide, leaving a band of practically pure feldspar. A stream, however, has followed the dike down the hill and has so thoroughly percolated the dike that attempts to obtain satisfactory samples by removing a reasonable amount of the outer portion of the dike failed. No feldspar has been taken out, therefore no sample was taken.

BANDANA. OLD GOUGE MICA MINE. ANORTHOCLASE.

This mine (84) is on a ridge 150 feet above the Bandana-Penland road and 1 mile southeast of Bandana, Mitchell County, N. C. Galax, the nearest shipping point, is 2½ miles distant. This dike is about 3 feet wide where exposed and has been worked for a distance of 60 feet by open-cut. The pegmatite carries little quartz and a few scattered garnets. The mica is found chiefly along the walls. The dike strikes west and dips 75° S. The feldspar sampled is white and of high luster. Its deformation-temperature range is from 1,300° to 1,310° C., and it fuses to a semitransparent glass free from yellow tint.

Properties in standard porcelain mixture.

In this mixture the feldspar produces vitrification at 1,300° C., and at 1,350° produces slight warping. The color is equal to that of the standard trial. The translucency at 1,350° C. is 0.71 and the transmitted light is cream colored. Shrinkage of the plastic molded mixture from green to 1,350° C. is 15 per cent, the drying shrinkage being 3 per cent and the firing shrinkage 12 per cent. Under the raw-lead and fritted glazes the color is unaltered.

BEAVER CREEK. HAMILTON MICA MINE. MICROCLINE.

This mine is 2 miles northwest of Beaver Creek, Ashe County, N. C., on Elk Mountain. The nearest railroad is at Shouns Crossroads 23 miles northwest, too far for haulage.

It is a very coarse pegmatite dike averaging 6 to 8 feet thick, rich in feldspar, but never free from quartz particles. However, the feldspar appears to be uniform in quality. The strike is N. 20° E., and the dip

80° E. The mica is present in some parts of this dike as isolated pockets, in others scattered through the pegmatite, rendering those parts worthless as a source of feldspar. The dike material was sampled where free from mica. The tests gave the following results:

Deformation temperature range, 1,290° to 1,310° C. Color, when fused, free from yellow tint; only a slight milkiness.

Properties in standard porcelain mixture.

In the mixture this feldspar produces a vitreous mass at 1,300° C., and at 1,350° a very slight warping occurs. The color is equal to the standard trial. Fired at 1,350° C. it has a translucency of 0.66 and the transmitted light is cream colored. The total shrinkage is 15.8 per cent, drying shrinkage 3.4 per cent, and firing shrinkage 12.4 per cent. Under the raw-lead and fritted glazes the color is unaltered.

BEAVER CREEK. NORTH HARDIN MICA MINE. MICROCLINE.

This mine is 1½ miles west of Beaver Creek, Ashe County, N. C. The nearest shipping point is Shouns Crossroads, 24 miles northwest. This is too far for road haulage.

It is a narrow dike that has been worked extensively along the surface for mica. The strike is N. 20° E. and the dip 70° to 80° E. The dike averages about 6 feet thick and contains a band of microcline from 1 to 4 feet thick. A narrow band of anorthoclase is also present in a number of places. The wall rock is solid gneiss. The feldspar of this dike is very free from impurities, which are chiefly quartz and mica and a few scattered iron garnets. The microcline has a deformation temperature ranging from 1,295° to 1,310° C. When fused it becomes practically clear and shows no yellow tint.

Properties in standard porcelain mixture.

This feldspar in the mixture produces a vitreous mass at 1,300° C., and at 1,350° shows a slight tendency to warp. Its color is equal to the standard. Fired at 1,350° C. this feldspar produces a translucency of 0.74, and the transmitted light is cream colored. Total shrinkage is 16 per cent, drying shrinkage 3 per cent, and firing shrinkage 13 per cent. Under the raw-lead and fritted glazes the color is unaltered.

BURNSVILLE. RAY MICA MINE. ALBITE.

This mine (72), which has been one of the most productive mica mines in the county, is 3 miles southeast of Burnsville, Yancey County, N. C., on the south face of a ridge that runs off from Black Mountain. The nearest shipping point is Micaville, 4 miles east. The workings are scattered along the slopes of a cove and are all on the same dike, which strikes N. 40° E. and dips 85° SE. The dike has in the center a clean feldspar band averaging 5 feet wide, and numerous narrow bands with more or less quartz on both sides. Some of these narrow bands are separated from one another by thin quartz bands, but a large part of the dike could be hand cobbed and marketed as feldspar.

The upper portion of the mine has been worked by open-cut to a depth of 40 feet, below which shaft mining has been carried on to a depth of 110 feet. The dumps of this shaft consist very largely of marketable feldspar, which was sampled and analyzed with the following result:

Chemical analysis.

H_2O	0.20
SiO_2	68.18
Al_2O_3	20.12
Fe_2O_3	.05
TiO_2	Trace.
CaO	.85
MgO	.05
K_2O	.66
Na_2O	9.38
	99.49

Chemical analysis in 1901.[a]

SiO_2	63.55
Al_2O_3	20.20
K_2O	8.73
Na_2O	6.65
	99.13

The albite, which was exposed in abundance during the summer of 1911, has been tested with the following results:

Deformation temperature range, 1,270° to 1,275° C.; color, when fused at 1,330° C., an opaque white with no yellow tint.

Properties in standard porcelain mixture.

In this mixture the feldspar gives a vitreous mass at 1,275° C. and warps slightly at 1,330° C. The color is slightly bluish by comparison with pure-white trials. Fired at 1,350° C. the translucency is 0.65 and the transmitted light is cream colored. The total shrinkage at 1,350° C. is 15 per cent, which consists of 3 per cent drying shrinkage and 12 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

FRANKLIN. BURNINGTOWN MICA MINE. MICROCLINE.

This mine (18) is 3 miles southeast of Burningtown Bald, Macon County, N. C. The nearest shipping point is Franklin, Macon County, N. C.

The mine is in a pegmatite dike, rich in feldspar, and averages about 8 feet wide, which has in the middle a quartz band varying from 2 feet to 3 feet wide. Other lenses of quartz are numerous. The strike is generally west; the dip 80° N. Mica is found chiefly along the walls, and the main portion of the pegmatite is very clean. Mining has been for mica only. A similar feldspar is found in small quantity in the Wayah Bald mica mines (17), which are 3 miles southwest.

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[a] See Economy Paper No. 6, North Carolina Geol. Surv., pp. 49-50.

The mine comprises an open-cut 150 feet long and a tunnel 300 feet long penetrating the dike 125 feet. The pegmatite has a deformation temperature ranging from 1,305° to 1,320° C. Color, slightly milky when fused, but free from yellow tint.

Properties in standard porcelain mixture.

In the standard porcelain mixture this pegmatite gives a vitreous mass at 1,310° C. and warping is very slight at 1,350°. Color is equal to the standard trial. Translucency at 1,350° is 0.65. Transmitted light is cream colored. Shrinkage in the standard plastic porcelain mixture is 15.3 per cent, green to 1,350°. Under the raw-lead and fritted glazes the color is unaltered.

FRANKLIN. CAMPBELL-HIGDON MICA MINE. MICROCLINE.

This mine (47) is 1½ miles west of Watauga Gap on Cowee Mountain, Macon County, N. C. Franklin, Macon County, is 9 miles southwest and Dillsboro, Jackson County, is 12 miles northeast of this mine. Franklin has the advantage of better roads and shorter haul and Dillsboro the advantage of a slightly lower freight rate to northern markets.

The pegmatite is cut by two tunnels, and at one point is 10 feet thick, with a 4-foot quartz band in the center. Owing to a thick overburden of loose ground, mining has been very difficult. Since the most productive workings are partly kaolinized material adjoining the wall rock, the fresh pegmatite has not been thoroughly exposed and its extent can not be estimated. The operations are, however, on a steep mountain side, and the loose material could be economically removed in case open-cut mining for feldspar should be attempted.

The feldspathic portion of this dike has a deformation temperature ranging from 1,305° to 1,320° C., and on deformation becomes a pale milky white without yellow tint.

Properties in standard porcelain mixture.

In this mixture the feldspar produces vitrification at 1,300° C., and at 1,350° shows very slight warpage. The color is similar to the standard trial. The translucency is 0.67 and the transmitted light is cream colored. The shrinkage in plastic mixture, from green to 1,350° C., is 15.7 per cent. Under the raw-lead and fritted glazes the color is unaltered.

FRANKLIN. LISLE KNOB MICA MINE. ALBITE AND ANORTHOCLASE.

This mine (21) is on the southwest face of Lisle Knob, 1½ miles east of the Little Tennessee River and 5 miles north of Franklin, Macon County, N. C., which is the nearest shipping point. The deposit is a pegmatite lens about 30 feet thick and is opened by tunnel for a length of 75 feet and a depth of 35 feet. The strike is N. 10° E. and dip is 80° W. The east half of the lens contains many quartz bands and numerous clusters of iron garnets, but the west half is very clean except for iron garnets, which would necessitate careful sorting to obtain the highest possible grade of product. This lens is covered with about 40 feet of loose overburden, but the wall rock is a solid gneiss.

This deposit was carefully sampled; the feldspar was found to have the following chemical composition:

Chemical composition.

H_2O	0.30
SiO_2	65.40
Al_2O_3	20.70
Fe_2O_3	.10
TiO_2	Trace.
CaO	1.60
MgO	Trace.
K_2O	6.00
Na_2O	6.10
	100.20

The deformation temperature ranges from 1,260° to 1,265° C.; the color after fusion is dull white, free from yellow tint.

Properties in standard porcelain mixture.

In this mixture the feldspar gives a vitreous mass at 1,265° C., and warps slightly at 1,350°. The color is slightly blue by comparison with the standard trial. Translucency is 0.72 and transmitted light is cream colored. Total plastic shrinkage, when fired to 1,350° C., is 15.9 per cent. Under the raw-lead and fritted glazes the color is unaltered.

FRANKLIN. M'GUIRE PROSPECT. MICROCLINE.

This prospect (42) is at the head of McGuire Cove, on the southwest face of Tremont Mountain, 4 miles northwest of Franklin, Macon County, N. C., and 1 mile north of and 500 feet above the Franklin Andrews road. The nearest shipping point is Franklin. The formation is a dike of feldspar 10 feet in diameter where exposed, and bisected vertically by a band of sugar quartz 2 feet thick. This dike strikes southwest and dips south. The wall rock is Carolina gneiss, and at this point is very solid. The deposit is opened the width of the dike, and for a height of 15 feet and a depth of 8 feet into the mountain. An average sample of this deposit shows the following chemical composition:

Chemical composition.

H_2O	0.60
SiO_2	63.90
Al_2O_3	19.97
Fe_2O_3	.15
TiO_2	Trace.
CaO	.05
MgO	Trace.
K_2O	13.20
Na_2O	1.01
BaO	.70
	99.58

The deformation temperature range is 1,315° to 1,330° C. Color is milky when fused, but free from yellow tint.

Properties in standard porcelain mixture.

In the mixture this feldspar gives a vitreous mass at 1,310° C., and at 1,350° no warping is noted. The color is slightly, but positively, superior to the standard trial. Translucency at 1,350° C. is 0.68. Transmitted light is cream colored. Shrinkage in standard plastic porcelain mixture is as follows: Green to 1,350° C., 14.7 per cent. Under the raw-lead and fritted glazes the color is unaltered.

FRANKLIN. NEAL BRYSON MICA MINE. ALBITE.

This mine (20) is on the Franklin-West Mills road, on the east bank of the Little Tennessee River, 6 miles north of Franklin, Macon County, N. C., which is the nearest shipping point. The dike is from 2 to 12 feet wide. It strikes west and dips 70° N. at the east end and 30° S. at the west end. This mine has been worked only for mica, which generally follows the south wall. The dike is a feldspar-rich pegmatite, and has in the middle a quartz band varying in thickness from a few inches to about 3 feet. Mining operations consist of a number of shafts about 70 feet above the road and a tunnel crosscutting the dike at the road level. From the shafts the dike material was removed by stoping until the cutting of the tunnel recently made possible the removal of the material from below. The abandoned stopes in the old workings are filled with feldspar and quartz bowlders, but much feldspar has been dumped about the mouth of the shafts and the entrance to the tunnel.

The feldspar of this dike has a deformation temperature ranging from 1,295° to 1,300° C. As mined, it has a peculiar blue-gray tint but on fusing it becomes a pale-cream enamel.

Properties in standard porcelain mixture.

In this mixture the feldspar gives a vitreous mass at 1,300° C., and only a trace of warping at 1,350°. The color is slightly bluish, but is not discernible except by comparison with pure-white trials. In the porcelain mixture the translucency is 0.65 and the transmitted light is cream colored. The shrinkage, green to 1,350° C., is 15 per cent in standard plastic mixture. Under the raw-lead and fritted glazes the color is unaltered.

FRANKLIN. SHEFFIELD MICA MINE. MICROCLINE.

This mine is 2 miles north of Franklin, Macon County, N. C., on the east bank of the Little Tennessee River, in a dike about 12 feet wide which strikes west and dips 80° N. The dike consists of a number of distinct bands. The one adjoining the south wall is a low-grade pegmatite and carries the mica. A band of pegmatite rich in feldspar joins this on the north, and adjoining this is a band or lens of pure feldspar. This is separated from the north wall by a band of quartz. The feldspar-rich pegmatite where exposed is about 4 feet thick and the feldspar is 2½ feet thick.

Mining is difficult because the mine is below the level of the river during the winter months and water fills all openings.

The deformation temperature range of this feldspar is from 1,315° to 1,330° C. Color, milky when fused but free from yellow tint.

Properties in standard porcelain mixture.

In this mixture the feldspar gives a vitreous mass at 1,320° C., and at 1,350° shows no warping. Color is equal to the standard trial. Translucency fired at 1,350° is 0.67 with a cream tint. Total shrinkage is 14.8 per cent. This consists of 3 per cent drying shrinkage and 11.8 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

FRANKLIN. SOUTHERN CLAY CO. MINE. CRYSTALLINE ORTHOCLASE.

The orthoclase was obtained from beneath the Southern Clay Co. kaolin deposit at Franklin, Macon County, N. C. It occurs as clearly defined orthoclase crystals of milk-white color and was pulverized to pass a 150-mesh brass screen.

Chemical composition.

H_2O	0.50
SiO_2	64.30
Al_2O_3	19.64
Fe_2O_3	.08
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
BaO	.17
K_2O	14.00
Na_2O	1.32
	100.01

This feldspar has a deformation temperature ranging from 1,305° to 1,325° C., and when fused to a glass becomes clear and without a trace of color that can be detected by the eye.

Properties in standard porcelain mixture.

In the mixture this feldspar shows vitrification at 1,300° C., and at 1,350° only a slight warpage. The color is a purer white than that of the standard trial. The translucency is 0.67. Total plastic shrinkage is 13.8 per cent when fired to 1,350°. Under the raw-lead and fritted glazes the color is unaltered.

GALAX. YOUNG AND RAY PROSPECT.

This prospect (74–75) is on the Black Mountain R. R. between Galax, Mitchell County, and Micaville, Yancey County, N. C. The pegmatite is a coarse aggregate of feldspar and quartz with a liberal sprinkling of biotite and garnet. The greatest width of the "deposit" is 200 to 250 yards but approximately one-half of this width is country rock and the remainder comprises lenses and bands of pegmatite of varying widths; the broadest area recorded is four bands, all of impure pegmatite but free from wall material, which has a total width of 75 feet. The only band of pure feldspar recorded is one 6 feet in width in the middle of this 75-foot pegmatite area.

JEFFERSON. COLDIRON PROSPECT.

This prospect is 3½ miles northeast of Jefferson, Ashe County, N. C., and due southeast from the Witherspoon mica mine. The dike where exposed is pegmatite, about 50 per cent feldspar and 50 per cent quartz, and contains few garnets or other objectionable material. The face of the dike for a depth of 15 feet is exposed along the south side of the Jefferson-Spartan road. The width of the dike is 15 to 18 feet. There are no pure feldspar bands and the mine is 25 miles from the railroad. No further examination was made.

JEFFERSON. WITHERSPOON MICA MINE. MICROCLINE.

This mine is on the southeast face of Little Phoenix Mountain, 3½ miles northeast of Jefferson, Ashe County, N. C., and one-half mile north of the Jefferson-Sparta road.

The pegmatite dike is about 10 feet thick and strikes N. 40° E. The dip of the exposed portion is vertical. Mica had been mined at two points about one-fourth mile apart previous to 1901. The dike is chiefly feldspar. The mica is largely in the bands adjoining the wall rock and no associated minerals besides quartz are noted. The feldspar band of this deposit was sampled and analyzed. The chemical composition is as follows:

Composition of feldspar.

H_2O	0.90
SiO_2	64.48
Al_2O_3	19.43
Fe_2O_3	.01
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
K_2O	13.19
Na_2O	1.84
	99.85

The deformation temperature range is from 1,290° to 1,310° C. When fused the feldspar shows only a trace of cloudiness and is free from yellow tint.

Properties in standard porcelain mixture.

In the mixture this feldspar produces a vitreous mass at 1,300° C., and at 1,350° shows very slight, if any, warping. The color is fully equal to the standard trial. Fired at 1,350° C. this mixture has a translucency of 0.72 and the transmitted light is cream colored. Total shrinkage of 15.4 per cent, drying shrinkage 3 per cent and firing shrinkage 12.4 per cent. Under the raw-lead and fritted glazes the color is unaltered.

PENLAND. CAROLINA MINERAL CO. MINE. MICROCLINE AND ALBITE.

A broad lens (110) is exposed on both sides of the North Toe River, one-fourth mile east of the railroad station at Penland, Mitchell County, N. C. The dike that includes this lens strikes about west; on the north side of the river it dips 75° to 80° S., and on the south side 80° to 85° S. The dike is 15 to 35 feet wide and contains isolated lenses of soda feldspar, but most of the dike is microcline. It contains little quartz, which is present chiefly as bands along the walls or as isolated lenses. Mica is found in pockets, and in places garnets are associated with the mica. Uranium-bearing minerals are also present, and many nugget-like masses containing pitchblende have been found in mining operations. Small quantities of beryl also have been found.

Quarrying began in the spring of 1911. Regular quarrying methods have been used so far, tunnels being used for prospecting purposes only. A depth of 50 feet has been reached. The deposit remains uniform to that depth with no indication of narrowing.

An average sample of the microcline constituting this dike was analyzed, and is as follows:

Composition of microcline.

H_2O	0.30
SiO_2	65.68
Al_2O_3	19.08
Fe_2O_3	.14
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
K_2O	13.09
Na_2O	2.08
	100.37

This feldspar has a deformation temperature ranging from 1,290° to 1,310° C. It fuses to a glass with only a trace of milkiness and no yellow tint.

Properties in standard porcelain mixture.

In the mixture this feldspar produces a vitreous mass at 1,295° C.; at 1,350° no warping is apparent. The color is fully equal to the standard trial. When fired at 1,350° C. the translucency is 0.69 and the transmitted light is cream colored. The total shrinkage at 1,350° is 15.6 per cent, 3.6 per cent being drying shrinkage and 12 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

An average sample of the albite in this dike is found to have the following chemical composition:

Composition of albite.

H_2O	1.00
SiO_2	64.92
Al_2O_3	22.28
Fe_2O_3	.21
TiO_2	Trace.
CaO	1.60
MgO	Trace.
K_2O	1.10
Na_2O	9.20
	100.31

The deformation temperature range is from 1,260° to 1,265° C. At 1,350° the feldspar fuses to a dull white mass.

Properties in the standard porcelain mixture.

In the mixture this feldspar produces a vitreous mass at 1,265° C., and at 1,330° there is a slight warping. The color of the porcelain at 1,350° is bluish when compared with the standard trial. The translucency at 1,350° is 0.65; the transmitted light is cream colored. The total shrinkage is 14.8 per cent, which is 2.4 per cent drying shrinkage and 12.4 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

PENLAND. FLAT ROCK MICA MINE. MICROCLINE.

This mine (97) is 1½ miles northeast of Penland, Mitchell County, N. C. The dike is from 8 to 12 feet thick, the center only being pure feldspar, which is from 4 to 6 feet wide. The dike strikes N. 35° E. and dips 80° SE. It is more or less altered to a depth of about 30 feet, below which the material is fresh.

An analysis of this feldspar, made by the North Carolina Geological Survey,[a] is as follows:

Composition of feldspar.

SiO_2	65.15
Al_2O_3	19.04
CaO	.12
Na_2O	7.00
K_2O	7.28
	98.59

This deposit has only recently been worked for feldspar.

PLUMTREE. AVERY MEADOW MICA MINE. ANORTHOCLASE.

This mine (107) is 1½ miles north of Plumtree, Avery County, N. C., and one-half mile west of North Toe River, the nearest shipping point being 8 miles southwest at Sprucepine. It has been worked extensively for mica. The coarse pegmatite dike carries a 4-foot band of clean feldspar midway between the walls. There is a band of nearly equal width of high-grade pegmatite adjoining the feldspar. The dike strikes N. 40° W. at the entrance to the tunnels, but farther in the strike varies, although always having a general northwest direction. This feldspar has no undesirable associated minerals, except the quartz and mica, which are not mixed with the feldspar but are confined chiefly to those bands of the dike that adjoin the walls.

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[a] See North Carolina Geol. Surv. Economic Paper No. 6, p. 49.

The great drawback to the mining of the feldspar is the fact that work would have to be under ground, since the overburden exceeds 50 feet in all places and is more than 100 feet deep over most of the dike.

The chemical composition of the feldspar from this deposit is reported as follows:

Composition of feldspar.[a]

SiO_2	62.95
Al_2O_3	19.66
K_2O	8.39
Na_2O	7.64
	98.64

The feldspar of this deposit was sampled and tested. It deforms only from 1,325° to 1,350° C., which is at least 30 degrees higher than might be expected from the analysis. Its color is slightly creamy when fused.

Properties in standard porcelain mixture.

In the mixture the feldspar produces a vitreous mass at 1,330° C.; it shows no warpage at 1,350° C. Its color, however, is grayish when fired to 1,350° C. Its translucency is 0.60 when fused at 1,350°, and its total shrinkage is 16 per cent. Under the raw-lead and fritted glazes the color is unaltered.

PLUMTREE. JOHNSON MICA MINE. MICROCLINE.

This mine (106) is 2 miles east of Plumtree, Avery County, N. C., on Plumtree Creek. Sprucepine, the nearest shipping point, is 10 miles southwest.

There is a pegmatite dike of variable thickness, containing a band of microcline from 2 to 4 feet wide midway between its walls. The dike strikes northwest and dips 5° to 25° NE.

The feldspar band is very narrow but is free from impurity. The pegmatite band that joins the feldspar is also free from scattered mica and low in quartz.

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[a] See Pratt, J. H., "The mining industry in North Carolina during 1901," North Carolina Geol. Surv. Economic Paper No. 6, pp. 49-50.

The feldspar collected has a deformation temperature ranging from 1,270° to 1,290° C. When fused it is practically clear and has no yellow tint.

Properties in standard porcelain mixture.

In the mixture the feldspar produces a vitreous mass at 1,275° C., and no warping at 1,350°. Its color is pure white. When fired at 1,350° C. it gives the porcelain a translucency of 0.73, cream colored, and a total shrinkage of 15.4 per cent, 3 per cent drying shrinkage and 12.4 per cent burning shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

PLUMTREE. PLUMTREE MICA MINE. MICROCLINE.

The mine (103) is one-half mile east of Plumtree, Avery County, N. C., on Plumtree Creek, 8 miles northeast of Sprucepine, which is the nearest shipping point. A pegmatite dike 10 to 15 feet wide was exposed, first by regular open-cut methods and later by hydraulic mining. The overburden ranges from 3 to 6 feet deep. The central portion, averaging 5 to 6 feet wide, is pure feldspar with only a scattering of quartz. The dike strikes N. 25° W. and dips 30° NE. The open-cut and hydraulic mining have exposed a large amount of microcline. The feldspar was sampled and analyzed as follows:

Composition of feldspar.

H_2O	0.17
SiO_2	65.37
Al_2O_3	17.92
Fe_2O_3	.02
TiO_2	Trace.
CaO	.17
MgO	Trace.
K_2O	13.05
Na_2O	2.10
	98.80

The deformation temperature range of this feldspar is 1,270° to 1,290° C. When fused the feldspar is practically clear and without a tint of yellow.

Properties in standard porcelain mixture.

In the mixture the feldspar produces a vitreous mass at 1,270° C., and at 1,350° only a very slight warpage occurs. The color is equal to the standard trial. The translucency when fired at 1,350° C. is 0.65 and the transmitted light is cream colored. Total shrinkage at 1,350° C. is 15 per cent, 3 per cent drying shrinkage and 12 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

SPEEDWELL POST OFFICE. COX PROSPECT. MICROCLINE.

This prospect (63) is in a creek bed on the east face of Panther Knob 1 mile west of Speedwell post office, Jackson County, N. C. The nearest shipping point is Sylva, Jackson County, which is 10 miles north. The feldspathic material is a pegmatite dike which, from the surface indications, carries very little quartz and mica. Its strike is N. 55° E. The commercially valuable feldspathic material exposed has a width of about 6 feet. The sample taken shows a deformation temperature ranging from 1,300° to 1,325° C. When fused this feldspar is clear and free from tint.

Properties in standard porcelain mixture.

In the standard porcelain mixture this feldspar produces vitrification when fired to 1,300° C., and shows no warpage at 1,350°. Fired to 1,350° C., the color is equal to the standard trial, the translucency is 0.69, and the transmitted light is cream colored. The total shrinkage when worked plastic is 15.3 per cent. Under the raw-lead and fritted glazes the color is unaltered.

SPRUCEPINE. AMERICAN GEM & PEARL CO. MINE. MICROCLINE.

A pegmatite dike (102) which has been worked for aquamarine, one-half mile east of the Sprucepine-Marion road and 3 miles southeast of Sprucepine, Mitchell County, N. C., which is the nearest shipping point. The mine is on the slope of a low ridge and has been worked by an incline. In September, 1911, the workings were full of water and their inspection was impossible. Fine orthoclase of a very pale flesh tint predominates in the dump, and the reports of residents agree that the dike averages over 10 feet wide and consists principally of feldspar very free from mica, the chief associated materials being beryl and a little quartz, which occur chiefly along the walls. The wall rock is reported to be solid and to require no timbering. The dike strikes northeast and dips 80° S.

The deformation temperature range of the feldspar is 1,310° to 1,330° C. The feldspar fuses to a glass with little cloudiness and no yellow tint.

Properties in standard porcelain mixture.

In the mixture this feldspar when fired to 1,310° C. produces a vitreous mass which shows no warpage at 1,350°. The color is equal to the standard trial. Fired to 1,350° C., the translucency is 0.66 and the transmitted light is cream colored. The total shrinkage is 15.5 per cent, of which 3 per cent is drying shrinkage and 12.5 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

SPRUCEPINE. COOK MICA MINE. MICROCLINE.

This mine (108) is 2 miles west of Sprucepine, Mitchell County, N. C. Open-cuts lie on the northeast face of a spur of Little Chalk Mountain 400 yards south of North Toe River; 200 yards to the south and 100 feet higher a cut and a short tunnel expose another pegmatite dike. The nearest shipping point is Sprucepine, although the C. C. & O. Ry. follows the opposite bank of the North Toe River.

These dikes strike N. 30° E. and dip 80° SE. The lower dike exposed is broad and shows a band of feldspar 12 feet wide in places and averaging 8 to 10 feet wide. The largest feldspar band is cream-white, but the other smaller bands are pink. There is one small band of albite, but it is separated from the potash feldspar; hence it will cause no trouble in mining. The mica is generally in the flinty bands that adjoin the walls.

The upper dike, 6 to 9 feet wide, contains along the middle a band of feldspar averaging 4 feet wide. All wall rock appears solid. The country rock is gneiss. The cream-white feldspar band of the lower deposit has the following chemical composition:

Composition of cream-white feldspar band.

H_2O	0.40
SiO_2	64.93
Al_2O_3	19.45
Fe_2O_3	Trace.
TiO_2	Trace.
CaO	.05
MgO	Trace.
K_2O	12.46
Na_2O	2.54
	99.83

The deformation temperature range of this feldspar is from 1,290° to 1,310° C. The feldspar fuses to a glass with only a trace of milkiness and no yellow tint.

Properties in standard porcelain mixture.

This feldspar in the mixture produces a vitreous mass at 1,300° C., and at 1,350° shows no evidence of warping. The color is equal or superior to the standard trials. When fired at 1,350° C. the translucency is 0.74 and the transmitted light is cream colored. The total shrinkage is 15.8 per cent, 3 per cent being drying and 12.8 per cent burning shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

SPRUCEPINE. ENGLISH KNOB MICA MINE. MICROCLINE.

This mine (95) is 2½ miles northeast of Sprucepine, Mitchell County, N. C. The property has been worked for mica at various points along the strike of the dike for about 200 feet, the general strike being N. 40° E. This pegmatite seems to be of uniform quality and a large percentage of pure feldspar is found. The width of the feldspar band varies from 5 to 12 feet.

At the present time the workings do not permit sampling at much depth. The surface material, however, indicates a good prospect.

SPRUCEPINE. WISEMAN MICA MINE. ALBITE AND ORTHOCLASE.

This mine (94) is near the head of Beaver Creek, 2 miles north of Sprucepine, Mitchell County, N. C., which is the nearest shipping point.

The tunnels on the southwest slope of the mountain have all caved but one. In this the dike strikes nearly west; the dip varies greatly. The feldspar-rich pegmatite averages not more than 4 feet wide where exposed, but it is low in quartz content and doubtless could be made marketable by some cobbing. Orthoclase is present in small isolated masses, but the greater portion of the dike is albite, of which the analysis follows:

Composition of albite.[a]

SiO_2	64.85
Al_2O_3	19.90
K_2O	2.91
Na_2O	10.04
	97.70

This material has a deformation range of 1,290° to 1,295° C. and fuses to an opaque white mass.

Properties in standard porcelain mixture.

In the mixture this feldspar produces vitrification at 1,295° C., and at 1,330° produces slight warping. The color is slightly bluish when compared with a standard white porcelain trial. When fired at 1,350° C. the translucency is 0.62 and the transmitted light is cream colored. The total shrinkage is 15.4 per cent, of which 3 per cent is drying shrinkage and 12.4 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

GRANITE.

Throughout Mitchell County there are vast areas of coarse granite that contain a high percentage of feldspar. There is always some small mica, but not sufficient to justify mining. There are outcrops in the Sprucepine-Marion road just south of Sprucepine and (100) on the face of Big Chalk Mountain just west of Sprucepine. The granite generally occurs as sills and appears very free from any impurities except the quartz and mica. The general strike is west.

Samples of this granitic material show the following chemical composition:

Composition of granitic material.

H_2O	0.90
SiO_2	75.10
Al_2O_3	15.57
Fe_2O_3	.47
TiO_2	.03
CaO	1.10
MgO	Trace.
K_2O	3.49
Na_2O	2.86
	99.52

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[a] See North Carolina Geol. Surv. Economic Paper No. 6, pp. 49-50.

This material has a deformation temperature range from 1,300° to 1,315° C. The micaceous material present is too high in iron and imparts to the pulverized granite when fused a pronounced cream-yellow tint.

Properties in standard porcelain mixture.

This material does not produce vitrification in the mixture until 1,310° C. is reached; at 1,350° warping is detected. The color of the porcelain produced is cream. The translucency when fired at 1,350° C. is 0.62 and the transmitted light is cream-yellow. The total shrinkage is 13.6 per cent, 4.4 per cent drying and 9.2 per cent firing shrinkage. Under the raw-lead and fritted glazes the color is unaltered.

VIRGINIA.

LOWRY STATION. M'NICHOLS CO. MINE. MICROCLINE AND ALBITE.

The mine is on the Thompson place in Bedford County, Virginia, 5 miles south of Lowry Station on N. & W. Ry.

There are two dikes exposed on the west slope of a ridge that runs north and south. The strike is N. 40° E., the dip 75° N. The south dike, where exposed, is about 20 feet wide. In the middle is a band of pure feldspar, varying from 4 to 7 feet wide, with pegmatite on each side. This pegmatite, however, is rich in feldspar, and if care were exercised to eliminate the mica scattered through it much marketable feldspar could be obtained. This south dike is opened 25 feet into the hill, being exposed for a depth of 40 feet and across its full width. The north dike is separated from the south dike by about 30 feet of country rock. The north dike shows no band of pure feldspar but is very rich in feldspar throughout its width of about 10 feet. This pegmatite is very coarsely crystalline and has considerable coarse muscovite scattered through it. Very little material has been removed from this part.

Feldspar from the south dike was analyzed and shows the following chemical composition:

Composition of feldspar.

H_2O	0.10
SiO_2	68.75
Al_2O_3	18.56
Fe_2O_3	.03
TiO_2	Trace.
CaO	1.25
MgO	Trace.
K_2O	6.85
Na_2O	4.29
	99.83

The deformation temperature ranges from 1,260° to 1,265° C. The fused feldspar forms an opaque white mass.

Properties in standard porcelain mixture.

This feldspar in the mixture produces a vitreous mass at 1,265° C.; at 1,350° only slight warping occurs. The porcelain shows a very faint bluish tint. Fired at 1,350° this feldspar produces a translucency of 0.64 and the transmitted light is cream colored. The total shrinkage is 15 per cent, drying shrinkage 3 per cent and firing shrinkage 12 per cent. Under the raw-lead and fritted glazes the color is unaltered.

SEMIKAOLINIZED FELDSPAR MINES AND PROSPECTS.

NORTH CAROLINA.

BAKERSVILLE. FLUKIN RIDGE MICA MINES.

These mines (81) are on a ridge 2½ miles south of Bakersville, Mitchell County, N. C., and one-half mile west of the Bakersville-Ledger road. The nearest shipping point is Toecane, 3½ miles northwest. This ridge contains a large number of dikes of partly decomposed pegmatite, which strike N. 50° E., dip 65° S. Some of these dikes contain a large amount of fine quartz, but others contain very little quartz. No large masses of quartz are exposed in any of the workings. Tunnels and shafts have been dug over an area one-half mile long and one-eighth mile wide and more or less of this semikaolinized material (locally called "flukin") is found in every case.

This material has altered so that it may be crushed to sand with the hand. A dike free from quartz was sampled and analyzed; it showed the following composition:

Composition of semikaolinized feldspar.

H_2O	1.34
SiO_2	63.32
Al_2O_3	20.45
Fe_2O_3	.07
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
K_2O	14.20
Na_2O	.80
	100.18

Calculated from the analysis, the mineral composition of this material is as follows:

Mineral composition of semikaolinized feldspar.

Microcline	84.0
Albite	6.8
Kaolinite	9.2
	100.0

The deformation temperature range of this material is from 1,330° to 1,350° C. The fused material is almost clear but has a slight gray tint.

Properties in standard porcelain mixture.

Introduced on the basis of its calculated mineral constitution, this material gives a vitreous mass at 1,330° C. The color is slightly gray by comparison with a standard trial. Fired at 1,350° C. the material has a translucency of 0.70 and the transmitted light is cream colored. The total shrinkage is 15.4 per cent, 3 per cent being drying and 12.4 per cent firing shrinkage. Fired under the raw-lead and fritted glazes this mass has the same faint grayish tint.

BEAVER CREEK. SOUTH HARDIN MICA MINE.

This mine, which is described under "Kaolins," is 1½ miles southwest of Beaver Creek, Ashe County, N. C. The dike was found to contain, where exposed, only semikaolinized feldspathic materials, which seem to be of very nearly uniform quality. The entire width of the dike was sampled and analyzed; it showed the following composition:

Composition of semikaolinized feldspar.

H_2O	7.30
SiO_2	53.00
Al_2O_3	29.20
Fe_2O_3	.21
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
BaO	.00
K_2O	9.92
Na_2O	.53
	100.16

The mine at the present time is so far from the railroad and the percentage of alkali in the sample taken is so low that the present availability of the material as a substitute for feldspathic material is doubtful. The color, however, appears to be sufficiently good for this purpose. If lower levels should show considerable quantities of semikaolinized material, it doubtless will some day be available as a flux material for pottery. On the other hand, if the dike lower levels prove to be completely altered, as in certain sections which were exposed by the owners but are now closed by caving, the dike may become a source of kaolin.

BRYSON. HARRIS CLAY CO. MINE.

This mine (3) is 2 miles north of Bryson, Swain County, N. C. The dikes from which the kaolin has been obtained are not uniform in degree of kaolinization. Many sections of these dikes are only slightly kaolinized and at a few points fresh feldspar is found. A large amount of this semikaolinized material can be obtained from this mine. This material was sampled and analyzed; it showed the following chemical composition:

Composition of semikaolinized feldspar.

H_2O	0.94
SiO_2	63.60
Al_2O_3	20.40
Fe_2O_3	.32
TiO_2	Trace
CaO	Trace
MgO	Trace.
BaO	.00
K_2O	14.40
Na_2O	.50
	100.16

The deformation temperature range is from 1,330° to 1,350° C., and the material fuses to a slightly milky mass free from yellow tint.

From the above chemical analysis this material is calculated to have the following mineral composition:

Mineral composition of semikaolinized feldspar.

Orthoclase	85.4
Albite	4.2
Kaolinite	9.4
Quartz	1.0
	100.0

Properties in standard porcelain mixture.

Introduced on the basis of its calculated mineral constitution, this material gives a vitreous mass at 1,350° C. and the color is equal to the standard trial. Fired at 1,350° C. the translucency is 0.70 and the transmitted light is cream colored. The total shrinkage is 15.6 per cent, of which 3 per cent is drying and 12.6 per cent is firing shrinkage. Tested under the raw-lead and fritted glazes this porcelain showed no change in tint.

FALLSTON. FRANK BAXTER MICA MINE.

This mine is 13 miles northeast of Shelby and 3 miles southeast of Fallston, Lincoln County, N. C., and 1 mile north of the Thomas Baxter mica mine. It is in a semikaolinized pegmatite dike, as indicated by the dumps, but the workings have fallen in and little idea of the extent of the dike can be obtained. The general strike of the dike as indicated by the shafts is northeast.

A quantity of this semikaolinized material, exposed in one shaft about 12 feet deep, was sampled and tested. It has a combined-water content of 12.4 per cent and when fired to 1,330° C. shrinks 15 per cent. Its refractory value is 1,670° C.

FRANKLIN. GURNEY CLAY CO. MINE.

This mine (29) is 4 miles north of Franklin, Macon County, N. C. The semikaolinized feldspar is exposed by an old tunnel for mica 250 feet southwest of the present workings for kaolin. The material occurs as a lens and has a general north strike. The material is pure white, and resembles kaolin, but possesses a bonelike texture and no plasticity. It contains 13.1 per cent of combined water and has a refractory value of about 1,700° C.

This material is too low in water to be halloysite and hence must be classed as kaolinite.

FRANKLIN. MOORE MICA MINE.

This mine (36) is 1½ miles north of Franklin, Macon County, N. C., on the west bank of the Little Tennessee River.

The dike, which is more or less kaolinized, averages about 9 feet thick; it has a general northeast strike and dips almost vertically. The overburden averages about 25 feet thick. The dike is very free from associated minerals and no large quartz bands are exposed. A portion of this dike is completely kaolinized, but large amounts of the feldspar are only slightly altered. A sample of slightly altered material showed the following chemical composition:

Composition of semikaolinized feldspar.

H_2O	2.05
SiO_2	63.74
Al_2O_3	20.90
Fe_2O_3	.12
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
BaO	1.10
K_2O	11.70
Na_2O	.19
	99.80

The mineral composition calculated from this analysis is as follows:

Mineral composition of semikaolinized feldspar.

Microcline	72.0
Albite	1.7
Kaolinite	17.6
Quartz	8.7
	100.0

The deformation temperature range of this material is from 1,350° to 1,370° C. The material fuses to a slightly milky glass with no yellow tint.

Properties in standard porcelain mixture.

Introduced on the basis of its calculated mineral constitution, the material gives a vitreous mass at 1,350° C.; its color is equal to the standard trial. Fired at 1,350 C. the translucency is 0.68 and the transmitted light is cream colored. The total shrinkage is 15.6 per cent, of which 3 per cent is drying and 12.6 per cent is firing shrinkage. Tested under the raw-lead and fritted glazes this porcelain shows no change of tint.

FRANKLIN. SOUTHERN CLAY CO. MINE.

This mine (40) was worked entirely for kaolin, but throughout the dike lenses of semikaolinized material were found. At the upper levels the semikaolinized material is loose and very light. It has a combined-water content of 8.65 per cent and deforms at 1,590° C., although it is translucent at 1,350° C.

These lenses are hardly large enough to be of industrial importance.

Where mining has reached a depth of about 80 feet the dike is only partly kaolinized, and at greater depths the kaolinization decreases until material approaching feldspar in appearance and composition is found.

This slightly kaolinized feldspar was sampled. Analysis showed it to have the following chemical composition:

Composition of semikaolinized feldspar.

H_2O	1.40
SiO_2	62.47
Al_2O_3	21.00
Fe_2O_3	.05
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
BaO	.30
K_2O	13.62
Na_2O	.60
	99.44

The mineral composition of this material is calculated as follows:

Mineral composition of semikaolinized feldspar.

Orthoclase	82.0
Albite	5.0
Kaolinite	8.0
Quartz	5.0
	100.0

The semikaolinized feldspar has a deformation temperature range from 1,350° to 1,370° C. It fuses to a glass only slightly milky and free from yellow tint.

Properties in standard porcelain mixture.

Introduced on the basis of its calculated mineral constitution, this material gives a vitreous mass at 1,350° C., and its color is equal or superior to the standard trial. Fired at 1,350° the translucency is 0.70 and the transmitted light is cream colored. The total shrinkage is 15.5 per cent, of which 3 per cent is drying and 12.5 per cent is firing shrinkage. Tested under the fritted and raw-lead glazes this porcelain shows no change in tint.

In order to determine the effect of washing, a quantity of the material was subjected to the standard laboratory washing process. The residue having a hydraulic value of more than 0.17 was analyzed and found to have the following chemical composition:

Composition of residue of hydraulic value more than 0.17.

H_2O	0.40
SiO_2	63.21
Al_2O_3	21.08
Fe_2O_3	.08
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
BaO	.30
K_2O	14.03
Na_2O	.60
	99.70

The material is thus seen to have lost a part of its kaolinite, thus lowering its deformation temperature. This is further shown by firing since the washed material has a deformation temperature range from 1,340° to 1,360° C.

MARSHALL. SETH FREEMAN PROSPECT.

This prospect is at the junction of Bear Creek and Marshall roads, on Trail Branch of Sandy-Mush Creek, 4 miles south of Marshall, Madison County, N. C., which is the nearest shipping point.

This dike is about 100 feet wide, but with many intruded horses of wall rock, so that few bands occur more than 8 feet thick. The strike is N. 40° E. and the dip 20° SE. The material sampled has the appearance of a fine white sand. It was found to have the following chemical composition:

Composition of semikaolinized feldspar.

H_2O	5.42
SiO_2	65.05
Al_2O_3	22.39
Fe_2O_3	.29
TiO_2	.12
CaO	Trace.
MgO	Trace.
BaO	.30
K_2O	6.53
Na_2O	.21
	100.31

From the chemical analysis this material is calculated as having the following mineral composition:

Mineral composition of semikaolinized feldspar.

Microcline	39.50
Albite	1.80
Kaolinite	37.10
Quartz	21.60
	100.00

Its deformation temperature range is 1,450° to 1,470° C., and it fuses to a slightly milky glass, with a faint yellow tint.

Properties in the standard porcelain mixture.

Introduced on the basis of its calculated mineral constitution, this material gives a vitreous mass at 1,350° C., and the color of the mass shows no trace of the yellow tint noted in the fused material, but is fully equal to the standard trial. Fired at 1,350° C. the translucency is 0.68 and the transmitted light is cream colored. The total shrinkage is 15.4 per cent, 3 per cent being drying and 12.4 per cent firing shrinkage. Tested under the raw-lead and fritted glazes this porcelain showed no change in tint.

MONTVALE. REED MICA MINE.

This mine is 2½ miles southeast of Sapphire and 1 mile northeast of Montvale, Jackson County, N. C.

It is in a dike of slightly kaolinized feldspar about 5 feet thick, but carrying a 2-foot quartz band in the middle. The dike strikes N. 25° E. and dips 40° NW. The feldspathic material is friable, but retains its crystalline structure.

The feldspathic portion of the dike contains 2 per cent of combined water. The deformation temperature range of the material is from 1,355° to 1,370° C. The material becomes a semiopaque mass on fusing.

Properties in the standard porcelain mixture.

This material, tested on a basis of 85 per cent feldspar, 10 per cent kaolinite, and 5 per cent quartz, produces a vitreous porcelain at 1,330° C. The color is cream white. The material has translucency of 0.64 when fired at 1,350° C. The total shrinkage is 15.7 per cent, of which 3 per cent is drying and 12.7 per cent is firing shrinkage. No increase in color intensity is noted under the raw-lead or fritted glazes.

RUTHERFORDTON. ISINGLASS HILL MICA MINE.

This mine is on a low ridge 3 miles north of Rutherfordton, Rutherford County, N. C., adjoining the line of the Southern Railway. There are no shipping facilities nearer than Rutherfordton, however.

This pegmatite dike varies from 6 to 50 feet in diameter and is nearly one-fourth mile long. The general strike of the deposit is N. 20° E. and the dip is 80° to 85° W.

This dike is bisected by a quartz band 1 to 3 feet wide. The portion west of this quartz band is practically pure kaolin, whereas the portion east of it is semikaolinized material. The associated minerals of this dike are a few scattered iron garnets and numerous nodules of wad. The mica is found adjoining the walls, is generally solid, and could be easily removed.

This semikaolinized material was sampled and analyzed; it has the following composition:

Composition of semikaolinized feldspar.

H_2O	3.60
SiO_2	60.47
Al_2O_3	23.45
Fe_2O_3	.10
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
K_2O	12.10
Na_2O	.65
	100.37

From this analysis the mineral composition of the material has been calculated to be as follows:

Mineral composition of semikaolinized feldspar.

Orthoclase	71.5
Albite	5.5
Kaolinite	23.0
	100.0

This material has a deformation temperature ranging from 1,350° to 1,390° C., and fuses to a semiopaque glass with no yellow tint.

Properties in the standard porcelain mixture.

Introduced on the basis of its calculated mineral constitution, this mineral gives a vitreous mass at 1,330° C. The color is fully equal to the standard trial. Fired at 1,350° C. the translucency is 0.70 and the transmitted light is cream colored. The total shrinkage is 15.5 per cent, 3.2 per cent drying and 12.3 per cent firing shrinkage. Fired under the fritted and raw-lead glazes this mass is unchanged in tint.

SYLVA. FOREST HILL MICA MINES.

These mines (64) are 10 miles south of Sylva and 1 mile west of Cullowhee Creek in Jackson County, N. C. The nearest shipping point is Sylva. The mines are in a semikaolinized pegmatite dike situated along the northeast slope of a spur of Panther Knob. This dike is extensive; it has been crosscut for more than 30 feet and tunnels along the strike have been run for more than 100 yards. The dike material is largely feldspar in various stages of decomposition. A large part, however, is only slightly kaolinized and retains the characteristic orthoclase structure and cleavage and its alteration is evidenced only by its friability, it being readily crushed with the fingers. It is pure white in color and is entirely devoid of plasticity, even when pulverized. A quantity of this material was sampled and by chemical analysis found to possess the following composition:

Composition of semikaolinized feldspar.

H_2O	0.90
SiO_2	63.35
Al_2O_3	20.07
Fe_2O_3	.15
TiO_2	Trace.
CaO	.03
MgO	Trace.
K_2O	13.70
Na_2O	1.11
	99.31

This material so closely resembles feldspar that it can be utilized as a flux for fine porcelain. Its mineral composition is, approximately, as follows:

Mineral composition of semikaolinized feldspar.

Orthoclase	81.8
Albite	9.5
Kaolinite	8.2
Quartz	.5
	100.0

The deformation temperature ranges from 1,310° to 1,340° C. When fused the material is free from yellow tint and only very slightly milky.

Properties in the standard porcelain mixture.

When introduced into the mixture in proportions based upon its mineral constitution this material produces a vitreous mass at 1,330° C. The color is equal or superior to the standard trial. The translucency is 0.74 and the transmitted light is cream-white. The total shrinkage is 15.2 per cent, 3 per cent being drying and 12.2 per cent firing shrinkage. No change in color is noted under the raw-lead or fritted glazes.

Another section of this dike shows material more kaolinized. This material contains 6.96 per cent combined water, and has a deformation temperature of 1,510° C.; hence it could be used only in a limited way to replace feldspar as an alkali-bearing material in the porcelain mass. Its color is pure white. By calcination the combined water may be removed, producing a material of low shrinkage. (See also feldspar and kaolin under this name.)

TOECANE. BENNER MICA MINE.

This mine (83) is on the south slope of Sink-Hole Ridge and one-half mile west of Flukin Ridge, Mitchell County, N. C. The nearest shipping point is Toecane, which is 4 miles northwest.

The kaolinized pegmatite dike is broad. Some of it is completely altered to a high-grade kaolin, and a large part apparently lacks only the plasticity to make it perfect kaolin. Very little fine quartz and no large quartz is found in this dike. The strike is N. 60° E. and the dip 75° S. There are four shafts and a tunnel besides numerous pits.

This nonplastic kaolin was sampled and tested. It contains 11.3 per cent combined water, and has a refractory value greater than 1,700° C. When fired alone at 1,330° C. it has a total shrinkage of 15.25 per cent, 3 per cent drying and 12.25 per cent firing shrinkage. Color is pure white, free from specks. The raw-lead and fritted glazes make no changes in the tint of the mass.

BAKERSVILLE. HAWK MICA MINE.

The Hawk mica mine (88) is about 3 miles east of Bakersville, Mitchell County, N. C. Operations were by tunnels, and most of these are now caved and closed. Two tunnels on the south side of the hill show a small dike of semikaolinized feldspar that is much stained by associated iron-bearing clays, but doubtless would be less stained at greater depth. No fresh feldspar or kaolin is exposed in either tunnel.

TULIP POST OFFICE. HOLE MICA MINE.

This mine is on a ridge above Dan River near Tulip, Stokes County, N. C., 16 miles southwest of Stuart, Patrick County, Va., which is the nearest shipping point.

The semikaolinized pegmatite dike nearly 25 feet thick strikes west and dips 30° N. Three bands of quartz, each moro than 4 feet thick, occur in this dike, and apparently lie along the walls and midway between. Another band of pegmatite is said to occur below the lowest exposed quartz band, but the opening that exposed it has been refilled. Between these massive quartz bands are numerous pegmatite bands of varying quartz content and some of these narrow bands are much iron-stained, making mining difficult if this stained material must be eliminated.

The two exposed bands of semikaolinized pegmatite were sampled and found to contain 13 per cent and 13.2 per cent, respectively, of combined water. Fired to 1,330° C. the material shrinks 15 to 15.3 per cent and becomes a pale-cream color. Its refractory value is above 1,700° C.

KAOLIN MINES AND PROSPECTS.

GEORGIA.

CLAYTON. MARK BECK PROSPECT.

This prospect is 8 miles east of Clayton, Rabun County, Ga., and 1½ miles south of the Clayton-Highlands road. It has been worked for mica by an open-cut. The dike has a general north strike and dips about 80° E. Where exposed it is about 10 feet wide and contains in the middle a band of sugar quartz from 3 to 4 feet thick. The surface of the dike is almost completely kaolinized, but at a depth of only 10 feet the kaolinization seems to be complete only in spots and at 15 feet the material is only semikaolinized. The dike doubtless is fresh feldspar and pegmatite at no great depth. The present opening is about 30 feet long, and about 5 feet of the dike adjoining the quartz band on both sides is apparently a good grade of feldspar or feldspar-rich pegmatite, the rest of the dike being a low-grade pegmatite.

JASPER. DAVIS MINE.

This mine is 4½ miles south of Jasper, Pickens County, Ga., which is the nearest shipping point. A well-defined dike about 10 feet wide lies along the crest of a low ridge and strikes about north. The maximum overburden is 4 to 5 feet. The dike has been exposed for about 60 feet by an open-cut. The material seems to be very good quality, but the kaolin content seems to vary greatly, as some points appear to be almost pure sand whereas others appear to be almost pure kaolin. No well-defined mica-bearing bands are apparent, but the entire deposit contains a considerable percentage of fine white mica which appears to possess a high luster.

The dike was sampled across its entire face and yielded 27 per cent of kaolin and 12 per cent of fine white mica. The kaolin was tested. It has a refractory value of 1,730° C. and a color of grade 3. The shrinkage at 110° C. was 5.3 per cent and when fired at 1,350° C. was 14.4 per cent. The tensile strength was 20 pounds per square inch.

Properties in the standard porcelain mixture.

In the mixture this kaolin has a translucency of 0.66 and the transmitted light is cream colored. Absorption is 4.8 per cent. The color is grade 3. Dried at 110 C. the shrinkage is 3.5 per cent and fired at 1,350° C., 13.4 per cent. Tested under the raw-lead and fritted glazes the color remains unaltered.

NORTH CAROLINA.

ALMOND. HEWITT MINE.

This mine is 3½ miles south of Almond, in Swain County, N. C., and one-half mile west of the Little Tennessee River. Four exposures have been operated on this property (11–12–13–14). The last opening

(14) operated is a dike which runs north and dips 75° E. It is an impure granite-pegmatite, incompletely kaolinized. The bands are not well defined and the whole mass has reached a state comparable only with sand. In places the overburden has been removed and the dike worked as an open-cut. The dike varies from 20 to 30 feet thick and has been removed for 275 feet into the hill to a depth of 40 to 60 feet. The dike is on a ridge. The material has been removed in dump cars to a steep slope in the hill down which it has been dumped into a stock bin and from this has been removed as required to a field washing plant near by. This washing plant, operated by a 20-horsepower portable engine, consists of two ordinary clay washers and two sand wheels through which the crushed kaolin passes to mica-settling troughs. After passing the mica troughs the kaolin is conveyed by flume to the concentrating plant, which is one-half mile distant on the west bank of the Little Tennessee River. This plant comprises concentrating tanks and a press equipment, including cistern, pumps, and two standard filter presses.

From the presses the kaolin goes to three open-air drying sheds, averaging 100 by 14 feet.

Kaolin from this mine was sampled directly from the dike, and by the laboratory process shows a kaolin content of 20 per cent.

The kaolin has a refractory value of 1,650° C. In color it falls very slightly below the scale established, and for that reason has been called grade 6. The shrinkage in drying at 110° C. is 3.6 per cent and in firing at 1,350°, 8.7 per cent. When dried at 110° C. the kaolin has a tensile strength of 6 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture fired at 1,350° C. this kaolin gives a translucency of 0.66 and the transmitted light is yellow. Absorption is 1.9 per cent. The color is grade 6. The shrinkage when dried at 110° C. is 2 per cent; when fired at 1,350° C., 13.2 per cent. The color is not affected by the application of either the raw-lead or the fritted glazes.

ALMOND. HYDE PROSPECT.

This prospect (9) is in Swain County, N. C., 2 miles east of Almond, on the east side of the Little Tennessee River. The deposit opened is an expanded lens covering practically the whole of a ridge 1½ to 2 acres in area. It is opened by five test holes and two tunnels, at an average elevation of 200 feet above the river, on both sides of the ridge, which has a direction N. 20° E. The lens is very irregular and possesses no uniform dip. The best exposure on this property was in the tunnels, one having a length of 75 feet and exposing a clear width of dike material of only 20 feet. This tunnel was sampled from a point 30 feet from the entrance to the end, a distance of 45 feet. The material at the end is 60 feet below the crest of the ridge.

The material collected was washed by the standard laboratory process and yielded only 19 per cent of kaolin. This kaolin was tested. It has a refractory value of 1,670° C. The color is grade 6. Dried at 110° C. the kaolin shrinks 4.2 per cent and fired at 1,350° C., 8.8 per cent. The tensile strength is 8 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.64 and the transmitted light is yellow. Absorption is 2.2 per cent. The color is grade 6. The shrinkage when dried at 110° C. is 2.1 per cent, and when fired at 1,350° C., 12.8 per cent. Tested under the raw-lead and fritted glazes the color is unaffected.

ALMOND. MESSER PROSPECT.

This prospect (10) is 2½ miles south of Almond, Swain County, N. C., on the west side of the Little Tennessee River. Two tunnels on opposite sides of the knoll and 25 feet below the crest expose a kaolin deposit running across the knoll. The dike appears to have a north strike and the dip where exposed is vertical. The material in these tunnels contains a fair quality of kaolin, but the dike contains a great many narrow streaks of stained material which greatly reduce the value of the deposit at this point. The openings are 200 feet above Little Tennessee River, and undoubtedly the dike at a lower point would show material of a much higher grade.

ASHEVILLE. SNIDER PROSPECT.

This prospect is on a small tract of land 3½ miles west of Asheville, N. C., on the Asheville-Alexander road. It is on the north bank of French Broad River and is 550 yards north of the Southern Railway, which here follows the river. The dike has a total width of 8 to 10 feet where exposed, but contains a number of horses of wall rock. This exposure, however, goes only 16 feet below the surface and can not indicate the dike structure at lower levels. The dike strikes N. 30° E. and dips 75° SE. The material is somewhat sandy and carries a large amount of white mica, most of which is in very small particles, has a bright luster, and is an ideal material for the pulverized-mica industry. Similar dikes along the general strike of this one are exposed for half a mile, but only by small pits, and no statement as to the quality of their material is attempted. The occurrence of a considerable deposit of dikelike formation 1 mile distant was noted, but found to contain a bluish-white sand similar to the deposits in the neighborhood of Almond, Swain County, N. C. The material in the Snider prospect was sampled and yielded 24 per cent of kaolin and 9 per cent of white mica.

The kaolin showed under test a refractory value of above 1,730° C. Its color is grade 3. The shrinkage when dried at 110° C. is 4.2 per cent and fired at 1,350° 14 per cent. The tensile strength of this kaolin is 24 pounds per square inch.

Properties in standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.67 and the transmitted light is cream colored. Absorption is 4.8 per cent. The color is grade 3. The shrinkage when dried at 110° C. is 3 per cent and fired at 1,350° C. 12.8 per cent. Tested under the raw-lead and fritted glazes the color remains unaltered.

BAKERSVILLE. AMERICAN MICA & MINING CO. MINE.

This mine (89) is in an isolated lens of kaolin on the brow of the hill 1 mile south of Bakersville, Mitchell County, N. C. The dike strikes northeast and shows a width of about 12 feet of good-quality kaolin. Attempts, however, to prove the extent of this material in either direction have failed. The deposit is doubtless an expanded lens of kaolinized material belonging to a dike that is exposed 300 yards to the southwest by a shaft on this same property and there shows 5 to 6 feet of kaolin.

A careful attempt to locate the dike at intermediate points by borings made at 3-foot intervals failed to expose any dike material, and it is therefore concluded that the dike between these points must be very narrow.

BAKERSVILLE. BENNER MICA MINE.

This mine (82) is on the south face of Sink Hole Ridge, 3 miles southeast of Bakersville, Mitchell County, N. C. The greater part of the dike where exposed on this property is semikaolinized material. The northwest part of the dike, however, appears to be isolated by a broad band of wall rock from the rest of the dike, and into this part four shafts have been sunk along the strike. These shafts have been abandoned and at the time of inspection no means was available for getting to the bottom of them.

The material removed from this part of the dike, as indicated by the dumps, is a good plastic kaolin. The width of this kaolin, however, is reported by men who worked in the mine as very narrow, at some places not exceeding a few feet. The length of the exposure developed by the shafts is reported to be only a few rods. Inability to inspect the dike prevented a more complete report.

BAKERSVILLE. THOMAS HOWELL PROSPECT.

This prospect (81) is on Flukin Ridge 2½ miles south of Bakersville, Mitchell County, N. C., and west of the Bakersville-Sprucepine road. This prospect was also sampled for semikaolinized feldspar. (See p. 108.) At one point a considerable quantity of fine white kaolin is encountered. There are, however, occasional streaks of fresh feldspar and on all sides of the lens there is semikaolinized material; these facts justify the assumption that the kaolin is merely an isolated lens and would not justify the equipment of an extensive outfit for handling it, although the presence in the neighborhood of other isolated kaolin deposits would justify the sinking of shafts and the removal of this kaolin to a central washing plant, if one were provided.

BAKERSVILLE. AARON M'KINNEY PROSPECT.

This prospect (86) is 1 mile northeast of Bakersville, Mitchell County, N. C., and 3 miles from Toecane, the nearest railroad point.

The dike is about 30 feet wide, including two horses of mica gneiss averaging between 6 and 8 feet thick where exposed. The dike occurs along a ridge and has been proven for about 300 yards. Its strike is northeast and its dip is nearly vertical. The pegmatite of the dike is almost completely kaolinized and contains numerous small pockets of micaceous material heavily stained with iron. The removal of these pockets without contamination of the white kaolin would demand much care in mining. This dike has been opened by two tunnels along and one across the dike, besides a number of test holes. The kaolin material in this dike was sampled; by a laboratory washing process it yielded 32 per cent of kaolin.

This kaolin has a refractory value above 1,730° C. and its color is grade 2. When dried at 110° C. it shrinks 4.4 per cent and when fired at 1,350° C., 12.9 per cent. The tensile strength of this kaolin dried at 110° C. is 28 pounds per square inch.

Properties in standard porcelain mixture.

This material in the mixture when fired at 1,350° C. has a translucency of 0.61 and the transmitted light is cream colored. Absorption is 4.25 per cent. The color is grade 2. Dried at 110° C. the shrinkage of the kaolin is 2.8 per cent, fired at 1,350° C. it is 10.6 per cent. Tested under the raw-lead and fritted glazes this mass shows a pronounced green tint, equally apparent under both glazes.

BAKERSVILLE. JOHNSON M'KINNEY MICA MINE.

This mine (87) is 1 mile northeast of Bakersville, Mitchell County, N. C., and is a continuation of the Aaron McKinney prospect situated due southwest. This mine has been worked more or less for mica but the operations have been entirely by shaft and the openings have all been allowed to fill with refuse, making a sampling of this mine impossible without great expense.

BAKERSVILLE. SINK-HOLE RIDGE PROSPECT.

This prospect consists of irregular dikes, doubtless expanded lenses, occurring in what is known as the Sink Hole, a ridge with a sunken crest, about 3 miles southeast of Bakersville, Mitchell County, N. C., and about 3 miles from Toecane, the nearest railroad station. The property has been thoroughly mined for mica and the more or less kaolinized material in the various dikes has been so mixed with wall rock and other impurities that the opening of a kaolin mine would be almost impossible. The depth of mining in some places reached 40 feet and in others did not exceed 30 feet. The material found is invariably more or less kaolinized but the larger part is high quality as regards color. The present workings are all in a semikaolinized part of the dike and the abandoned workings are completely closed by refuse from the later workings. Consequently this statement on the composition of the dike materials at different points is based on examination of the dumps. The inability to obtain material directly from the dike made further investigation unadvisable.

BEAVER CREEK. SOUTH HARDIN MICA MINE.

This mine is 1½ miles southwest of Beaver Creek, Ashe County, N. C. The pegmatite dike is 6 to 10 feet wide, strikes N. 40° E., and dips 60° SE. It has been exposed by open-cuts and shafts and one tunnel following the strike. The material is kaolinized to a very uniform extent wherever exposed, but in no exposures has kaolinization proceeded far enough to cause the development of plasticity, although it is reported that in old shafts now entirely closed by slides a good grade of plastic kaolin was exposed. However, the dike material which was carefully sampled fails entirely to fall under the kaolin classification, and it is therefore reported as semikaolinized feldspar.

BETA. LOVE PROSPECT.

This prospect is 1 mile east of Beta, Jackson County, N. C., on the north side of the Murphy Branch of the Southern Railway. This prospect is opened on a low isolated hill adjoining the railway and as the test holes are now almost completely filled with refuse no idea of the extent of the deposit can be obtained. However, the dumps from these holes indicate that kaolin of fair quality occurs here.

BOONFORD. YOUNG PROSPECT.

This prospect (76) is 1 mile west of Boonford, Yancey County, N. C. The dike averages about 30 feet in width and contains a 4-foot horse of wall rock in the middle. It strikes northeast and dips

85° S. The material in the deposit adjoining the northwest wall and on the north side of the band of wall rock is very much more advanced in kaolinization than is the material on the southeast side of this band. The entire dike is free from impurities except for a very small amount of garnet sand occurring in small pockets. This dike has been proven for only a short distance, but the surface indications are that it is partly exposed several yards distant along the strike in both directions. However, the topography is so irregular that a thorough proving by test holes and tunnels, if necessary, would alone settle this point.

Material from this dike, where exposed by tunnel, was sampled. By the laboratory washing process this material yielded 22 per cent of kaolin having a refractory value above 1,730° C. and a color of grade 2. When fired at 1,350° C. the shrinkage of this kaolin is 12.6 per cent; dried at 110° C. the shrinkage is 4.8 per cent. This kaolin dried at 110° C. has a tensile strength of 22 pounds per square inch.

Properties in standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin shows a translucency of 0.76 and the transmitted light is cream colored; absorption is 6 per cent. The color is grade 2 and the shrinkage when dried at 110° is 4 per cent, and fired at 1,350° C., 12.4 per cent. When tested under the raw-lead and fritted glazes no change of tint is apparent in this mass.

BRYSON. CAROLINA CLAY CO. MINE.

This mine (7) is at the head of Buckner Branch, 4 miles southwest of Bryson, Swain County, N. C. It is reported as having been entirely worked out but continuations of the dike or similar dikes (6 and 8) occur both to the north and south of this worked deposit. The dike is about 16 feet wide. It strikes N. 15° E., and dips about 75° W. It is rich in kaolin along the west wall but becomes progressively poorer toward the east wall, along which the dike material is practically all sand. Numerous pockets of garnet-colored sand and bands of the wall rock are noted.

The clay-washing plant erected for use in connection with this mine has fallen into decay but there is doubtless considerable valuable material still at this mine, and certainly on adjoining prospects, which could be washed from this plant.

A sample of the dike material from across the full width of the dike yielded by the laboratory washing process 22 per cent of kaolin. This kaolin was tested and found to have a refractory value of 1,650° C. Its color is grade 5 and shrinkage 3.8 per cent when dried at 110° C., and 10.2 per cent when fired at 1,350° C. The tensile strength is 8 pounds per square inch.

Properties in the standard porcelain mixture.

In the mixture fired at 1,350° C. this kaolin has a translucency of 0.65 and the transmitted light is yellow. Absorption is 2.2 per cent. The color is grade 5. When the material is dried at 110° C. the shrinkage is 2.4 per cent, when fired at 1,350° C. it is 13.5 per cent. Tested under the raw-lead and fritted glazes the color remains unaltered.

BRYSON. EVERETT PROSPECT.

This prospect (5) is on a ridge above Watkins Branch, one-half mile east of the main road and 2 miles northwest of Bryson, Swain County, N. C. The width of the dike could not be determined positively, but from surface indications it is 9 to 10 feet wide. The prospect is due southwest from the Harris Clay Co. mine, and 1½ miles distant. The dike contains very few large flint bowlders, but a considerable proportion of semikaolinized material. The deposit was sampled as thoroughly as possible, and the material collected, when washed by the standard laboratory process, yields 28 per cent kaolin. The refractory value of this kaolin is above 1,730° C. Its color is grade 3; its shrinkage when dried at 110° C. is 4.3 per cent, fired at 1,350° C. 12.6 per cent. The tensile strength is 15 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture fired at 1,350° C. this kaolin has a translucency of 0.65 and the transmitted light is cream colored. Absorption is 4.7 per cent. The color is grade 3. Dried at 110° C. the shrinkage is 3 per cent, fired at 1,350° C. it is 12.2 per cent. Tested under the raw-lead and fritted glazes the color remains unaltered.

BRYSON. HARRIS CLAY CO. MINE.

This mine (2) is on the east slope of a ridge 2 miles north of Bryson, Swain County, N. C. The dike varies from 40 to 60 feet wide, but contains many bands of the material that forms the wall rock. The dike, which is faulted at intervals of about 150 feet, strikes N. 20° E. Its average of flint content is low, but it varies considerably in degree of kaolinization, so that the kaolin content obtained by washing the material of this deposit is less than might reasonably be expected. In many parts of the dike the material is yellow and of low grade in color; spurs of the dike at the same points, however, are of pure material, free from stain. The dike has been practically worked out over the area within which the material was found to contain a commercial quality of kaolin. A similar dike (4) was opened 1 mile southwest, but was abandoned after a few months' work. Good material has been located (1) 3 miles northeast of the Harris mine. Mining was by open-cuts to a depth of about 35 feet and by shafts below. The overburden is handled with wheelbarrows and dump carts, and its removal has been a simple problem because the dike is along the face of a very steep ridge. The kaolinized material was handled in steel hopper cars, by which it was taken to the edge of the slope, where it was emptied into the cars of a gravity railway, by which it was carried a distance of 200 yards down the mountain and there automatically dumped into the storage bins. From these bins it was shoveled by hand into a flume, which was supplied with water from a brook near by. This flume carries the material one-half mile to the washing plant, where the regular system of washers and sand wheels is used to remove the coarse material. The fine material passes to a sand-settling trough and thence to the mica-settling troughs and over a battery of screens into another flume. The washed material, practically pure kaolin, is conveyed 1½ miles to the concentrating plant, which is in the valley. This concentrating plant consists of concentrating tanks and a battery of two filter presses. The pressed kaolin is dried in open-air sheds and is then ready for market.

Samples of the material as mined were taken from the part of the dike being worked in the autumn of 1911. This material washed by the standard laboratory process yields 22 per cent of kaolin. This kaolin was analyzed and found to have the following chemical composition:

Composition of kaolin.

H_2O	14.10
SiO_2	46.95
Al_2O_3	37.24
Fe_2O_3	.40
TiO_2	.05
CaO	Trace.
MgO	Trace.
Na_2O	.24
K_2O	.49
	99.47

The refractory value of this kaolin is above 1,730° C. The color is grade 3. Dried at 110° C. it shrinks 4 per cent, fired at 1,350° C. 12.8 per cent. The tensile strength is 14 pounds per square inch.

Properties in standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin has a translucency of 0.63; the transmitted light is cream colored. Absorption is 3.3 per cent. The color is grade 3. Dried at 110° C. the shrinkage is 2.8 per cent, fired at 1,350° C. 11.8 per cent. Tested under the raw-lead and fritted glazes the color is unaffected.

BURNSVILLE. KAOLIN OUTCROPS.

One-half mile north of Burnsville, Yancey County, N. C., a small kaolinized dike (68) that is exposed near the road has been worked in a small way for mica. The exposure is not large enough to justify any statement as to the kaolin content.

Two and a half miles east of Burnsville on the road to Micaville is an old mica mine (71). Although the shaft is closed by caving, the material above the mouth of the shaft shows considerable semikaolinized feldspar and some kaolin.

BURNSVILLE. ELIZABETH SMITH MICA MINE.

This mine (69) is 1½ miles east of Burnsville, Yancey County, N. C., on the north side of and 150 yards distant from the Burnsville-Micaville road, and 3½ miles west of Micaville, the nearest shipping point. The dike is from 25 to 35 feet in width, strikes N. 20° E., and has an irregular dip. The deposit contains a number of semikaolinized lenses, but for the most part is well advanced in kaolinization. Of the mine tunnels some have been driven to expose kaolin and others in a search for mica. Those for mica have been neglected and in most instances have fallen in. On the southwest end of the dike are two tunnels about 50 feet long, connected by a crosscut, which exposes practically the entire width of the dike. At this point the dike shows 6 feet of well-kaolinized pegmatite adjoining the west wall, 9 feet of semikaolinized material, and 20 feet of well-kaolinized pegmatite adjoining the east wall. The country rock is completely kaolinized and forms a yellow claylike material. About one-third mile to the north and on the general strike of this dike a somewhat narrower but otherwise similar dike is exposed. At various intermediate points similar dike material is exposed by test holes, indicating that the dike extends the entire distance, although its width and uniformity have not been proven. A smaller dike (70) is exposed by a pit south of the road and one-eighth mile west.

The two kaolinized bands exposed in the tunnel were sampled. When washed they yielded 44 per cent of kaolin, which showed the following chemical composition on analysis:

Composition of kaolin.

H_2O	13.10
SiO_2	45.95
Al_2O_3	39.20
Fe_2O_3	.05
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
BaO	.03
Na_2O	Trace.
K_2O	.50
	98.83

This kaolin has a refractory value above 1,730° C. and the color is grade 2. The shrinkage dried at 110° C. is 4.4 per cent; when fired at 1,350° C., 12.9 per cent. The tensile strength of this kaolin dried at 110° C. is 29.5 pounds per square inch.

Properties in standard porcelain mixture.

This kaolin in the standard porcelain mixture fired at 1,350° C. has a translucency of 0.7 and the transmitted light is cream colored. Absorption is 4.6 per cent, the color grade 2. The shrinkage when dried at 110° C. was 3.4 per cent and fired at 1,350° C. 14 per cent. Tested under the fritted and raw-lead glazes the mass has a very pale green tint that is equally apparent under either glaze.

DILLSBORO. ALLISON PROSPECT.

This prospect (50) is north of Barkers Creek, 3 miles west of Dillsboro, Jackson County, N. C., on a branch one-half mile from the creek. A dike is exposed at three points. These exposures have a general west direction over a knoll and the exposed dike appears to be extremely lenticular. The exposures indicate the presence of kaolinized pegmatite, but the work done does not expose the pure dike material; hence no samples were taken.

At a point 200 yards north (49) on the opposite side of the branch a short tunnel has penetrated a lens of pegmatite which is, where exposed, about 5 feet in diameter and semicircular in shape, the dike material being entirely covered by an arch of mica gneiss. The material thus appears to form distinctly a lens or pocket, and its extent can be proven only by further mining.

At a point one-eighth mile west of Barkers Creek Station a small kaolinized pegmatite dike is exposed in an abandoned mica shaft (48), but the workings have caved and the dike material can not now be reached.

DILLSBORO. ROBERT ASHE PROSPECT.

This prospect is 6 miles from Dillsboro, Jackson County, N. C., and one-half mile south of the main road between Webster and Cullowhee on the south side of Tuckasegee River. The kaolin was opened by a pit in a gap of the mountains, but the pit has completely fallen in and no kaolin is visible. The reported width is 14 feet. A small amount of kaolin is found in the dump, but much of this is only semikaolinized and considerable stained material is noted in connection with the kaolinized pegmatite. Mining for mica has been successful at various points in the neighborhood for a distance of one-fourth mile from this pit, and a more or less regular band of quartz extends in a general north-south direction from this deposit through the mica operations. Considerable further work is necessary to properly expose the kaolin at the old pit.

DILLSBORO. CAGLE GAP MICA MINE.

This mine (53) is 2 miles south of Dillsboro, Jackson County, N. C., and due south of the Dillsboro bridge across Tuckasegee River. The dike is opened in Cagle Gap by a pit at the road side, where it strikes N. 20° E. and is 15 feet wide. The material along the walls is very rich in kaolin and is well kaolinized, but the middle of the dike for a width of about 8 feet is a very low-grade material and is unevenly kaolinized. The entire deposit is rather sandy. The part rich in kaolin was sampled. Washed by the standard laboratory process, it yielded 21 per cent of kaolin. The refractory value of this kaolin is 1,730° C. and the color grade 4. Its shrinkage when dried at 110° C. is 5.8 per cent and fired at 1,350° C. 13.3 per cent. The tensile strength is 16 pounds per square inch.

Properties in the standard porcelain mixture.

In this mixture and fired at 1,350° C. the kaolin gives a translucency of 0.65 and the transmitted light is cream colored. Absorption is 5.4 per cent. The color is grade 4. The shrinkage when dried at 110° C. is 2.8 per cent and fired at 1,350° C. 12.6 per cent. Tested under the raw-lead and fritted glazes the color remains unaltered.

DILLSBORO. HARRIS CLAY CO. MINE.

This mine (60) is 5 miles southeast of Dillsboro, on the Murphy branch of the Southern Railway, Jackson County, N. C., which is the nearest shipping point.

The pegmatite dike is very large, 200 to 300 feet wide and about 800 feet long. It forms a ridge that trends nearly north. In the center of the ridge is a 30-foot band of sugar quartz, adjoining which on the west is a 30-foot band of gneiss. The kaolinized pegmatite next the quartz is very rich in kaolin and averages 25 to 40 feet wide; adjoining it on the east is a wide band of kaolinized pegmatite that has a high quartz content. On the west side of the gneiss band is another wide band of kaolinized pegmatite. As in all pegmatite dikes in this district numerous lenses of quartz and ferruginous sand are scattered through the deposit, but most of these lenses are well defined and may be removed by hand labor without injury to the adjacent material.

Several smaller dikes (59 and 58) averaging 10 to 15 feet wide have been opened on ridges to the west and north of the main dike. All have been opened about 100 feet above Little Savannah Creek.

The country rock of the district is Carolina gneiss which in this section is weathered to a maximum depth of 100 feet, the pegmatite being altered to about the same depth.

The overburden is principally weathered gneiss which has a golden-red color due to iron. Where the dike material is in place at the present surface of the country, this iron stain has filtered into it and rendered it practically valueless for a depth of 4 to 12 feet.

The overburden and the refuse dike material are removed by plow and scraper, which are supplemented by pick and shovel for the last foot above the valuable material. The removal of overburden proceeds usually 6 to 10 feet ahead of mining except where a quartz lens is encountered, when mining is continued up to the face of the quartz. The overburden walls are generally sloped about 70 degrees from the horizontal.

Surface water causes little annoyance because the hillsides are steep and the dike is opened almost in the crest of the ridge.

The method of mining is as follows: An open-cut, about 20 feet deep in the dike, is run along the face of the hill. The material is removed by pick and shovel and loaded into low cars which carry about 1,000 pounds each. They are pushed by hand or drawn by horse along a tramway to the edge of the hill where the material is dumped into a chute and water pumped in, which conveys the crude kaolin to the washing plant in the valley below.

For mining the lower portions of the deposit circular shafts are used. As the dike material at this point is kaolinized to a depth of about 100 feet, heavy timbering is necessary. The key-block system (see p. 68) is used. The material is loosened by pick and shovel, explosives being used only for breaking masses of quartz. The shafts are sunk in benches of about 4 feet. The standard type of hoisting bucket and a drum hoist operated by a horse are used.

At a depth of about 60 feet mining is somewhat hindered by water, which filters into the shaft. This is removed by the buckets in the same manner as the other material. When the bottom of the kaolinized material is reached, the robbing of the dike adjacent begins and proceeds by benches from the bottom to the top of the shaft, the timbering of each bench being removed and the bench being filled with waste from the surface before the level above is disturbed. This robbing and filling is worked in benches of about 4 feet, like shaft sinking.

The crude kaolin is carried by flume to the washing plant, where it passes through two clay washers in succession and then into a long narrow tank in which are two sand wheels. The coarse material removed by the sand wheels passes through a third clay washer and into another long vat in which are two sand wheels. The coarse material removed by these wheels is considered as waste. The kaolin obtained by this second washing is conducted by a trough to the mica troughs, where it mixes with the kaolin from the first battery of washers. The mica troughs are in two batteries, thus dividing the flow of slip. Stationary screens are used above the concentrating tanks. The water removed from these tanks is pumped to the head of the flume line and reused. The concentrated slip is pumped into filter presses. The clay cakes are dried principally in open-air sheds, although a steam drier is provided for "rush" orders. The dry kaolin is hauled to Dillsboro over a tramroad in cars drawn by horses.

Crude kaolin samples taken from this deposit and washed by the standard laboratory process yielded 49 per cent of kaolin. This kaolin was analyzed. It has the following chemical composition:

Composition of kaolin.

H_2O	13.99
SiO_2	46.95
Al_2O_3	37.73
Fe_2O_3	.15
TiO_2	.05
CaO	Trace.
MgO	Trace.
Na_2O	.18
K_2O	.60
	99.65

This kaolin has a refractory value above 1,730° C. Its color is grade 1. Its shrinkage when dried at 110° is 6.1 per cent; when fired at 1,350°, 12.7 per cent. Its tensile strength is 24 pounds per square inch.

Properties in standard porcelain mixture.

This kaolin when introduced into the mixture and fired at 1,350° C. has a translucency of 0.69 and the transmitted light is cream colored. Absorption is 5.8 per cent. The color of the mass when fired at 1,350° C. is grade 1. The shrinkage at 110° is 3 per cent and when fired at 1,350° C. is 12.6 per cent. When tested under the raw-lead and fritted glazes this mass shows a pale-green tint, equally apparent under each glaze.

FRANKLIN. BRYSON PROSPECT.

This property adjoins the West prospect on the west and is 8 miles north of Franklin, Macon County, N. C. The dike exposed has the same strike as that on the West prospect, but is opened at a level 50 feet lower by a tunnel 120 feet long. A width of nearly 15 feet of kaolin is exposed.

This dike was carefully sampled. Washed by the standard laboratory process the material yielded 38 per cent of kaolin. This kaolin has a refractory value above 1,730° C. and its color is grade 2. Dried at 110° C. its shrinkage is 6.6 per cent and when fired at 1,350° C., 17.3 per cent. The tensile strength is 28 pounds per square inch.

Properties in the standard porcelain mixture.

In the mixture fired at 1,350° C. this kaolin gives a translucency of 0.68 and the transmitted light is cream colored. Absorption is 4.5 per cent. The color is grade 2. The shrinkage when dried at 110° is 3.4 per cent and when fired at 1,350° C., 14 per cent. When tested under the raw-lead and fritted glazes this kaolin shows a very pale-green tint, equally apparent under each glaze.

FRANKLIN. CHALK MICA MINE.

This mine (30) is 2 miles north of the Franklin-Burningtown road and 6 miles northwest of Franklin, Macon County, N. C. The dike is from 15 to 20 feet in width. It strikes N. 30° E.; its dip is nearly vertical. The material varies from a very pure kaolin, exposed in a tunnel, to a very sandy kaolin, exposed in an open-cut 20 yards distant. It has only been proven for a distance of about 50 yards, but there is no reason to doubt that it extends a considerable distance farther south.

This material was sampled to give an average of the deposit so far as exposed and was washed by the standard laboratory process. The sample yielded 35 per cent of kaolin that has a refractory value above 1,730° C. The color is grade 3, but as the sample represented the entire deposit the elimination of a small portion of the poorer material would much improve the color. The shrinkage of this kaolin dried at 110° C. is 5.7 per cent and fired at 1,350° C. is 13.7 per cent. Its tensile strength when dried at 110° C. is 15.5 pounds per square inch.

Properties in standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.65 and the transmitted light is cream colored. Absorption is 6 per cent, and the color is grade 3. The shrinkage is 3 per cent when dried at 110° C., and when fired at 1,350° C. is 14.8 per cent. Tested under the raw-lead and fritted glazes this mass assumes a pale-green tint, equally apparent under either glaze.

FRANKLIN. FRANK PROSPECT.

This prospect (27) is 2½ miles northeast of Franklin, Macon County, N. C., on the Franklin-Dillsboro road. The dike of kaolinized pegmatite follows a ridge and strikes about west, varying from 12 to 15 feet wide. This dike contains little fine quartz and is covered by only about 8 feet of overburden. It has been opened by a number of shafts and a tunnel, and from the tunnel which offers the best opportunity for sampling an average sample was taken.

This sample when washed by the standard laboratory process yielded 31 per cent of kaolin. The refractory valuo of the kaolin is above 1,730° C., and the color grade 3. When dried at 110° C. it shrinks 5.4 per cent and when fired at 1,350° C. 15.1 per cent. The tensile strength of this kaolin is 18 pounds per square inch.

Properties in the standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.63 and the transmitted light is cream colored. Absorption is 4.9 per cent. The color is grade 3. The shrinkage when dried at 110° C. is 3 per cent and when fired at 1,350° C. is 13.2 per cent. Tested under the raw-lead and fritted glazes this kaolin shows a pale-green tint, equally apparent under either glaze.

FRANKLIN. FRANKLIN KAOLIN TO MICA CO. MINES.

These mines (23) are 4½ miles north of Franklin, Macon County, N.C., at Iotla Bridge on the west bank of Little Tennessee River. Franklin is the nearest railroad station. The mines were originally worked for mica, but have more recently been worked for kaolin, being the first for kaolin west of the Cowee Mountains. The development consists of 10 tunnels and about 12 shafts. Some of the shafts have reached a depth of 120 feet. It contains a number of well-defined bands of sugar quartz and these occur not only along the walls but also midway between the walls. The dike has been worked for 550 feet and varies in width from 10 to 100 feet, approximately. The pegmatite was remarkably low in quartz, yielding a very high-grade kaolin. The deposit is not completely worked out but has been abandoned. Only one shaft is in such a condition that the dike material can be studied, but the product of this mine had gained a reputation for high quality and fine color, and this shaft exposed kaolin which evidently represented a fair average of that in the dike.

This material was sampled and washed by the standard laboratory process and found to contain 42 per cent of kaolin, which has a refractory value above 1,730° C. Its color is grade 1, and its shrinkage when dried at 110° C. is 5.2 per cent and when fired at 1,350° C. is 12.4 per cent. The tensile strength is 24 pounds per square inch.

Properties in the standard porcelain mixture.

In the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.72 and the transmitted light is cream-white. Absorption is 6.2 per cent and color is grade 1. Dried at 110° C. the shrinkage is 3.2 per cent and fired at 1,350° C. the shrinkage is 12.8 per cent. The test under the raw-lead and fritted glazes shows that the color remains unaltered.

FRANKLIN. GURNEY CLAY CO. MINE.

This mine (29) is on the south side of Iotla Creek, 2 miles from the Little Tennessee River and 4 miles north of Franklin, Macon County, N. C.

The kaolinized dike forms an expanded lens, averaging about 200 feet in width and 300 feet in length already proven, located on the north slope of a low ridge. Similar material is exposed in an abandoned mica shaft (28) one-eighth mile northwest. The Gurney mine was opened first by shaft at the lowest point on the north edge of the lens, where the overburden was not more than 2 or 3 feet. Shafts were sunk higher up the hill which show that the overburden does not increase much. However, the cost of shaft mining became so great that open-cut mining was finally adopted. The open-cut has been advanced a depth of 20 to 30 feet into the lens and up to the present little quartz has been encountered. The lens consists of bands varying in kaolin content, some parts being very rich and others very low in kaolin. By mining the entire width of the dike, as nearly as possible, the operator is able to average this material and thus produce a product reasonably uniform in physical properties. Some of the shafts reach a depth of 100 feet, but below this level the degree of kaolinization hardly justifies mining.

The material from the shafts has been hoisted by horse whims. The water, which flows into the shaft rapidly below about 60 feet, has up to the present been removed in buckets, which differ in size only from those for hoisting the dike material. Handling the water in this manner is difficult, and attention is being given to the installation of pumps, but all pumps tested have proven unsatisfactory because the grit in the water rapidly cuts out and ruins the valves.

A tunnel from about the level of the creek bed, which is 100 feet below the open-cut level, is considered, and in this way the mine may possibly be drained effectively.

The material removed from the deposit, whether by open-cut or by shaft, is conveyed to a central point by tramcars and there is mixed in constant proportion and emptied into a flume, the water for which is pumped a distance of 500 yards. This flume conveys the dike material to the washing plant, which consists of two washers and a long trough in which are two sand wheels. From the sand wheels the material passes to a long sand trough and from the sand trough to mica troughs. The mica troughs of this plant are constructed with absolutely no drop from entrance to exit and the removal of the very fine sand and mica is therefore thorough.

From the end of the sand troughs the kaolin slip passes through a battery of stationary screens and then into settling tanks. In the settling process aluminum sulphate is used as an aid in concentration. It is placed in bags and suspended in the trough between the screens and the settling tanks, and is found as effective as the alum employed at other plants through this district. After the excess water is removed the kaolin slip is conveyed to a reservoir and thence pumped into the filter presses.

After leaving the filter presses the kaolin is dried by two systems. One is the standard steam-drier system, in which the steam pipes are placed directly on the floor, and on these pipes the damp kaolin is heaped. These pipes are open at one end so that the steam is under no pressure. The other system of drying is the open-air rack system. A building two stories high has in the upper story racks upon which the kaolin is spread; when dry this kaolin is dumped through the floor into the lower story, which is used for storage. This building has a ridge roof with an opening the full length along the ridge, covered with an additional narrow ridge roof, so that the escaping moisture from the drying kaolin passes off unretarded and does not condense on the underside of the roof as has been the case in some other drying sheds. The steam drier connected with this plant is 150 feet long by 24 feet wide. The open-air drier is 110 feet long by 24 feet wide and four racks high, each rack being 1½ feet deep.

The dike material was carefully sampled and yielded 42.5 per cent of kaolin. However, at the time of this sampling the richer part of the dike only was exposed and the kaolin yield of the entire dike will probably not exceed 30 per cent.

This kaolin was analyzed and found to have the following chemical composition:

Composition of kaolin.

H_2O	14.72
SiO_2	44.00
Al_2O_3	40.79
Fe_2O_3	.11
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
Na_2O	.07
K_2O	.55
	100.24

This kaolin has a refractory value above 1,730° C., and its color is grade 1. Dried at 110° C. it shrinks 5.4 per cent and fired at 1,350° C. it shrinks 11.9 per cent. The tensile strength is 27.5 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture fired at 1,350° C. the kaolin has a translucency of 0.72 and the transmitted light is cream-white. Absorption is 6.5 per cent. The color is grade 1. The shrinkage when dried at 110° C. is 3.2 per cent and when fired at 1,350° C. 12.4 per cent. Tested under the raw-lead and fritted glazes the color is not affected.

FRANKLIN. KASSON MICA MINE.

This mine (46) is 2 miles northeast of Franklin, Macon County, N. C., on the east side of the Franklin-Dillsboro road. The dike and its numerous stringers varying in width from 6 to 16 feet strike N. 40° E. and dip from 75° W. to 80° E. The mine has been worked only for mica but the dike where exposed is completely kaolinized and enormous quantities of high-grade kaolin have been ruined by mixture with wall rock in the dumps. The kaolinized dike is remarkably free from impurities except for small pockets of garnet-colored sand and altered biotite which is badly iron-stained. The presence of this iron stain would demand some care in mining but its coloring power in the burned product is very much less than would be expected from the appearance of the washed clay in which this iron stain is allowed to remain. The portion of the dike that is most completely kaolinized and contains the least proportion of the iron stain was sampled. The sample when washed by the standard laboratory process yielded 41 per cent kaolin which had a pronounced pink color from this stain. The kaolin, however, has a refractory value above 1,730° C. and its color is grade 3. Its shrinkage is 4.7 per cent when dried at 110° and 14.1 per cent when fired at 1,350° C. The tensile strength of this kaolin dried at 110° is 18 pounds per square inch. If the garnet-colored sand and altered biotite were carefully removed the kaolin produced would doubtless be improved in color at least one grade, but owing to the fact that this deposit is worked entirely by tunnels on the "ground-hog" system the present exposures are not extensive enough to justify a positive statement as to the possibility of working this dike for higher-grade kaolin.

Properties in standard porcelain mixture.

This kaolin in the mixture fired at 1,350° produces a translucency of 0.71 and the transmitted light is cream colored. Absorption is 5.6 per cent. The color is grade 3. Dried at 110° C. this mass shrinks 3.2 per cent and when fired at 1,350° C. the shrinkage is 13.3 per cent. When tested under the raw-lead and fritted glazes the tint of this mass is a very pale green, equally apparent under either glaze.

FRANKLIN. LENOIR PROSPECT.

This prospect (44) is 4½ miles west of Franklin, Macon County, N. C., on the Franklin-Andrews road. There is a dike averaging about 20 feet wide and exposed on the slope of a hill by two tunnels, one 20 feet below the other. The strike is west, the dip perpendicular. The kaolin exposed in the upper tunnel is free from bands or streaks of other material and has a small content of quartz. The material in the lower tunnel is more or less stained by small streaks of iron-stained sands at frequent intervals in the walls. The dike appears to be incompletely kaolinized in places, streaks of hard material almost approaching feldspar in appearance being encountered at frequent intervals, but most of these streaks are narrow. The lower tunnel contains a number of lenses or pockets of micaceous material embedded in stained kaolin, but they are small and doubtless could be easily removed.

The kaolin from this deposit was sampled. It yielded by washing 38 per cent of kaolin. The shrinkage of this kaolin at 110° C. is 6.4 per cent and at 1,350° C. is 14.9 per cent. The tensile strength at 110° is 20 pounds per square inch. The color is grade 1 and the refractory value is above 1,730° C.

Properties in standard porcelain mixture.

In this mixture the shrinkage at 110° is 3.6 per cent; fired at 1,350° C., 11.6 per cent. The translucency is 0.67 and the transmitted light is cream colored. The absorption is 7.1 per cent. The color is grade 1. Under the fritted and raw-lead glazes the color of the porcelain mixture is not altered.

FRANKLIN. LYLE PROSPECT.

This prospect (37) is 1½ miles northeast of Franklin, Macon County, N. C., on the Dillsboro road. It is a dike about 15 feet wide that strikes northeast and dips 75° NW. There is little fine mica or other impurity in the dike material, but the degree of kaolinization is variable. Proper sampling was impossible because the dike has been opened to a depth of only about 10 feet, and surface drainage may have removed much of the fine kaolin from this part of the dike.

The least-exposed part of the deposit was carefully sampled. The sample contains 26 per cent of kaolin when washed by the standard laboratory process. This kaolin has a refractory value of 1,690° C. and its color is grade 3. Its shrinkage when dried at 110° C. is 5.2 per cent and when fired at 1,350° C. is 15.8 per cent. The tensile strength of the kaolin dried at 110° is 16 pounds per square inch.

Properties in standard porcelain mixture.

This kaolin introduced into the mixture and fired at 1,350° C. gives a translucency of 0.67 and the transmitted light is cream colored. Absorption is 3.1 per cent. The color is grade 3. Dried at 110° the shrinkage is 3.3 per cent and when fired at 1,350° C. the shrinkage is 12.8 per cent. Tested under the raw-lead and fritted glazes there is no change in color.

FRANKLIN. M'GUIRE PROSPECT.

This prospect (43) is 4 miles northwest of Franklin, Macon County, N. C., on a west spur of Tremont Mountain, one-eighth mile south of the McGuire feldspar mine and on about the same elevation. The dike strikes northeast and dips 80° S., it is kaolinized and about 18 feet thick at this point. It is free from associated minerals but contains a small amount of semikaolinized material. There are two tunnels into the dike, but no material has been sold.

The material exposed was sampled and washed. It showed a kaolin content of 42 per cent. This kaolin has the following chemical analysis:

Analysis of kaolin.

H_2O	14.00
SiO_2	46.35
Al_2O_3	39.00
Fe_2O_3	.30
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
Na_2O	.00
K_2O	.50
	100.15

The shrinkage of this kaolin at 110° C. is 5.7 per cent, the tensile strength per square inch 27.5 pounds, the shrinkage when fired at 1,350° C. 10.5 per cent. The color is grade 3 and the refractory value is above 1,730° C.

Properties in standard porcelain mixture.

The shrinkage of this kaolin in the mixture at 110° is 3.2 per cent. When fired at 1,350° it has a shrinkage of 14.2 per cent and a translucency of 0.72; the transmitted light is cream colored. Absorption is 5.4 per cent. The color is grade 3. Under the fritted and raw-lead glazes the color remains unaltered.

FRANKLIN. PORTER MICA MINE.

About 2 miles west of Franklin, Macon County, N. C., is the old Porter mica mine (45). It has long been abandoned and the shafts have caved, preventing any proper sampling of the deposit. The dumps about the shafts show considerable kaolin of fair quality but no record of the dimensions of the dike is obtainable.

FRANKLIN. MOORE MICA MINE.

This mine (36) is 1½ miles north of Franklin, Macon County, N. C., on the west bank of the Little Tennessee River, about 80 feet above the river. The mine is reported to have been opened by tunnels several years ago but is now opened only by two shafts which do not cut the main dike. The section exposed by the shaft is 9 feet wide and shows kaolin very free from impurities and low in quartz. A considerable part of this dike, however, is not completely kaolinized. Where exposed it is covered with about 20 feet of overburden, strikes N. 40° E., and dips 85° N.

The kaolin material was sampled and by the laboratory washing process found to contain 34 per cent of kaolin. The refractory value of this kaolin is above 1,730° C. Its color when fired at 1,350° C. is grade 1; its shrinkage when dried at 110° C. is 7 per cent and when fired at 1,350° C. is 15.7 per cent. The tensile strength of this kaolin dried at 110° C. is 26 pounds per square inch.

Properties in standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin shows a translucency of 0.64. The transmitted light is cream white. Absorption is 7.6 per cent. The color is grade 1. The shrinkage when dried at 110° is 3 per cent and when fired at 1,350° C. 12 per cent. Tested under the fritted and raw-lead glazes this porcelain mixture assumes a pale-green tint.

FRANKLIN. MYERS PROSPECT.

This prospect (26) is due southwest from the Sloan prospect, about 4 miles below Franklin, Macon County, N. C. It is, however, on the south side of the Little Tennessee River and directly on the line of the strike of the dike on the Sloan prospect. The dike on the Myers prospect follows a low ridge and is exposed by small pits. It is opened at one point for a distance of 25 feet along the strike and shows a maximum width of 12 feet. The depth of the opening is only about 5 feet, which is not enough to properly remove the surface material; hence the actual quality of the dike could not be accurately determined. Indications of this dike continuing in both directions are evident from surface marks, but no work has been done to prove its continuation. As this property is on the south side of the Little Tennessee River its distance by road from the shipping point, which is Franklin, N. C., is about 3½ miles.

FRANKLIN. RABY MICA MINE.

This mine (32) is north of Tremont Mountain and on the west side of Halls Mill Creek, 1 mile west of Burningtown road and 4 miles from Franklin, Macon County, N. C.

The dike with a number of stringers has a total width of almost 100 yards, and strikes N. 10° E. across a ridge which runs almost due west and has a width of about one-fourth mile. The stringers average about 15 feet wide, and have been proven for about 200 feet on each side of the ridge and about 100 feet below the crest of the ridge. The kaolin penetrated by tunnels at low levels shows a higher sand content, undoubtedly because it is material accumulated by a slide or slip from the main body. Dikes of similar structure are exposed by prospect tunnels one-fourth mile north (31) and one-fourth mile east (33). A dike of lower grade (34) is exposed on a north slope one-fourth mile southeast of the Raby mine.

The kaolin material was carefully sampled and by the laboratory washing process yielded 45 per cent of kaolin. By analysis it showed a chemical composition as follows:

Composition of kaolin.

H_2O	13.80
SiO_2	46.90
Al_2O_3	38.60
Fe_2O_3	.25
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
Na_2O	.26
K_2O	.39
	100.20

This kaolin had a refractory value above 1,730° C. Its color when fired to 1,350° C. is grade 3. Its shrinkage when dried at 110° is 6.25 per cent, and when fired to 1,350° C. is 13.5 per cent. Dried at 110° this kaolin has a tensile strength of 21.5 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture when fired at 1,350° C. this kaolin gives a translucency of 0.71 and the transmitted light is cream colored. Absorption is 6 per cent. The color is grade 3. The shrinkage at 110° is 2.2 per cent, when fired at 1,350° C. 13.2 per cent. When the fritted or the raw-lead glaze is applied to the porcelain mixture the color of the body through the glaze appears to be a pale green and is as pronounced under one glaze as under the other.

FRANKLIN. ROCHESTER MICA MINE.

The location (22) is the same as the Lisle Knob mica mine, 5 miles north of Franklin, Macon County, N. C., but there is a kaolinized dike 150 feet to the east and 25 feet above the exposure of the fresh pegmatite dike. This kaolin seems to be remarkably pure and of very fine quality, but the dike contains many small iron garnets, which would make the mining of the kaolin somewhat difficult. The dike strikes N. 10° E. and dips 80° W., like the fresh pegmatite dike, is 5 to 10 feet in width, and seems to be very uniform from wall to wall. It has been exposed by tunnel along the strike for about 40 feet. This tunnel is 50 to 60 feet below the crest of the mountain.

The material was carefully sampled and washed and showed a kaolin content of 44 per cent. The kaolin was tested and found to have a refractory value above 1,730° C. The color is grade 2. The shrinkage when dried at 110° C. is 6.2 per cent and when fired at 1,350° C. is 13.8 per cent. The tensile strength of this kaolin dried at 110° C. is 24 pounds per square inch.

Properties in standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.70 and the transmitted light is cream colored. Absorption is 5.8 per cent. Its color is grade 2. Dried at 110° C. its shrinkage is 2.6 per cent, and fired at 1,350° C. is 13 per cent. Tested under the raw-lead and fritted glazes the tint of this mass is very pale green, equally apparent under either glaze.

FRANKLIN. SANDERS PROSPECT.

This prospect (24) is south of Lyle Knob and 5 miles north of Franklin, Macon County, N. C., on the road between Iotla Bridge on the Little Tennessee River and the Franklin-Dillsboro road. The kaolinized portion of the dike, about 20 feet wide, strikes N. 20° W. and follows the crest of a low ridge. It is remarkable in that it is clearly defined by quartz bands along its walls. In addition to the 20 feet of kaolin contained in this dike there is also a width of from 8 to 15 feet of low-grade pegmatite material. The dike is opened by a tunnel 120 feet long and was sampled at the face of this tunnel where its full width is exposed. The sample when washed yielded 29 per cent kaolin.

The refractory value of this kaolin is above 1,730° C. and the color is grade 3. The shrinkage when dried at 110° C. is 4.5 per cent, and when fired at 1,350° C. is 13.8 per cent. The kaolin has a tensile strength of 14 pounds per square inch.

Properties in the standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. the kaolin gives a translucency of 0.69 and the transmitted light is cream colored. Absorption is 5.3 per cent. The color is grade 3. Dried at 110° C. the shrinkage is 3.4 per cent, and fired at 1,350° C. the shrinkage is 13.5 per cent. Tested under the fritted and raw-lead glazes it shows a pale-green tint, equally apparent under each glaze.

FRANKLIN. SLOAN PROSPECT.

This prospect (25) is on the north side of the Little Tennessee River, 4 miles below Franklin, Macon County, N. C. The dike is from 8 to 10 feet wide, strikes northeast, and dips 80° NW. It is exposed by only a single open-cut 50 feet above the Little Tennessee River, and a proper study was therefore impossible. The cut is the width of the dike and about 8 feet into the face of the hill. The dike is completely kaolinized but contains a considerable quantity of fine quartz and a narrow quartz band on the northwest side along the hanging wall. There is much stained mica along the foot wall which would demand careful mining if to be eliminated.

The prospect was sampled. The sample washed by the standard laboratory process was found to contain about 30 per cent pure kaolin. The kaolin was tested and has a refractory value above 1,730° C. and the color is grade 3. The shrinkage when dried at 110° C. is 6.4 per cent, and when fired at 1,350° C. is 15.2 per cent. The tensile strength of the kaolin dried at 110° C. is 22 pounds per square inch.

Properties in standard porcelain mixture.

This kaolin introduced into the mixture and fired at 1,350° C. gives a translucency of 0.69 and the transmitted light is cream colored. Absorption is 7.1 per cent. The color is grade 3. Dried at 110° C. the shrinkage is 3.2 per cent, and fired at 1,350° C. is 12.3 per cent. Tested under the raw-lead and fritted glazes the tint of this mass is pale green, equally apparent under each glaze.

FRANKLIN. SMITH PROSPECT.

This prospect (15) is on Little Tellico Creek, 1½ miles southwest of Tellico Creek and 12 miles northwest of Franklin, Macon County, N. C.

The dike, which is completely kaolinized, is exposed by a 40-foot tunnel and by an open pit on a hillside 75 feet above Little Tellico Creek. The dike is nearly 200 feet wide but several broad horses of wall rock reduce the actual width of pegmatite material to about 50 feet. The dike has a general northeast strike and dips 80° W. where exposed. The pegmatite is reasonably free from foreign matter, the associated minerals being muscovite and quartz.

This material was sampled. On washing it yielded 39 per cent kaolin. This kaolin has the following chemical analysis:

Composition of kaolin.

H_2O	12.55
SiO_2	48.05
Al_2O_3	37.69
Fe_2O_3	.31
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
Na_2O	.02
K_2O	.91
	99.53

The shrinkage of this kaolin in drying at 110° C. is 6.8 per cent, and when fired at 1,350° C. is 12 per cent. Its tensile strength dried at 110° C. is 20.5 pounds per square inch. Its color is grade 4, and the refractory value is 1,670° C.

Properties in standard porcelain mixture.

In this mixture the kaolin showed a shrinkage dried at 110° of 3.2 per cent, fired at 1,350° of 12.4 per cent. The translucency at 1,350° C. is 0.71 and the transmitted light is cream colored. Absorption at 1,350° C. is 4 per cent. Color at 1,350° is grade 4. Tested under the raw-lead and fritted glazes the color remains unaltered.

FRANKLIN. SOUTHERN CLAY CO. MINES.

These mines (38 and 35, 41, 39) are on one of the foothills of Tremont Mountain, 1 mile northwest of Franklin, Macon County, N. C., and one-half mile north of the Franklin-Andrews road. They have been worked out since the preparation of this report began, but the deposit and the method of mining are of especial interest and are therefore described. The main workings (41) showed a well-defined kaolinized pegmatite dike, 16 to 20 feet wide, that has a broad band of sugar quartz along the north wall and another quartz band about midway in the dike. The wall rock is gneiss and the contact between the dike and the gneiss is very sharp, the stain from the decomposed gneiss rarely penetrating the dike more than 1 inch. This dike strikes almost due east and dips 70° S.

The kaolinized pegmatite contains as impurities small pockets of garnet sand and isolated patches of weathered biotite that are surrounded by a garnet-colored claylike material. This sand seems to have no tendency to stain adjacent material, but the weathering of the biotite invariably causes a stain for 3 or 4 inches in every direction. Very little sheet mica is found, but large quantities of first-class punch mica in plates from three-fourths inch to 2 inches wide have been removed and rejected with other refuse.

The mining of this dike was very expensive because shafts alone were used, no material being removed by open-cut work.

The overburden varies from 5 to 25 feet. The thick quartz bands in the hanging wall and in the middle of the dike also added much to the cost of mining, as their removal was absolutely imperative in sinking vertical shafts. These shafts were invariably sunk directly into the dike, and because of the dip they passed through it and into the foot wall, so that it was necessary to remove big masses of quartz, sink into the foot wall, and then run a crosscut from the bottom of a shaft in order to reach the kaolin.

The deposit for a depth of 25 feet into the dike shows a high grade of kaolin of fair plasticity. At about this depth irregular lenses of semikaolinized feldspar in the form of very fine sand were encountered in some of the shafts. Below this level much very fine kaolin is found, and to a depth of about 80 feet the kaolin content of the dike is in excess of what would be expected from the kaolinization of average pegmatite, and approaches very closely the theoretical maximum from the decomposition of feldspar. Below the 80-foot level the dike material soon changes to semikaolinized feldspar with isolated patches of plastic kaolin, and below the 100-foot level plastic kaolin is rarely found, but the material is a rich kaolinized feldspar containing very little quartz and is remarkably high grade as regards color. At this 100-foot level well-defined and practically fresh crystals of orthoclase are found embedded in the slightly kaolinized material.

This deposit is reasonably uniform for about 120 feet, but disappears almost completely on the east slope of the hill. Another dike which was supposed to promise considerable quantities of kaolin lies parallel to this dike and 30 yards south of it. This dike was explored by pits. The surface material proved to be stained, but as the high-grade material of the main dike was also stained near the surface the owners believed that the small dike would likewise improve in quality with depth. This, however, failed to be the case, and all the dike material was rejected as unmarketable.

On an isolated knoll one-eighth mile northeast of the small dike just described another well-defined dike was exposed by a shaft, but it proved merely an expanded lens and yielded kaolin in commercial quantities for only about 50 feet. Its maximum width was about 15 feet. Numerous other small dikes are on this property, but they were found to be too narrow to be profitably worked by shafts.

Mining was by circular shaft in the ordinary manner of this district, electric hoists being used to remove rock and kaolin from the lower levels.

Below about 45 feet the inflow of water caused great annoyance to the miners, and at 60 feet the removal of the water became a considerable problem. At lower levels the flow continued to increase until at 100 feet at least 50 per cent of the total time of operation was spent in removing the water, which was hoisted in barrels with bands and braces like the half barrels generally used to remove the dike material. The flow of water at times became so great that an extra crew of men had to be employed to enable the kaolin miners to work. Removal of this water in any other way than by bailing was never attempted, and it is not known whether this deposit could have been drained by tunneling, a method that has proved so successful in draining other deposits in this district.

The dike material was conveyed to the washing plant by flumes, the water for which was pumped from the valley below with a 3-cylinder pump. The larger proportion of semikaolinized material found at the lower levels of these shafts necessitated putting in screens to remove the large lumps of hard material which constantly clogged the flume and caused it to overflow. At the washing plant the material passed through two batteries, consisting of one washer and one sand wheel each; the refuse from the first sand wheel went into the second washer, but the kaolin from the first sand wheel went directly to the second sand wheel and not through the second washer. The material from this washing process passed into a shallow sand-settling tank 6 by 6 by 1½ feet deep. The outlet of this settling tank is at an angle of 45 degrees with the intake, thus giving the sand a better opportunity to settle. From this settling tank the kaolin-bearing material was conveyed by troughs to a rotary screen, where the greater proportion of the fine mica was removed. The finest material passed through 12 mica-settling troughs, each 40 feet in length, making the total length 480 feet, before it reached the 140-mesh screen which this company uses. Numerous screens were tested by this company, and the revolving screen was found to be the most efficient and economical for its work.

The kaolin passing through the screen ran into a trough that contained a battery of electromagnets for the removal of any iron that may have been taken up by contact with the machinery in the washing process. From these magnets the material passed over a bed of alum which aided the settling of the clay slip and simplified the removal of the excess water. The material then passed to the settling tanks where the excess water was removed. From the settling tanks the material was pumped into a cistern that was constantly agitated, and from this the slip was pumped to the filter presses, where most of the kaolin was removed. The pressed kaolin from the filter presses was loaded on rack cars, which were run into a tunnel drier heated by hot air obtained by forcing air through steam coils with fans. The floor of the drier has a slight grade, sufficient to cause the cars to move forward when the car next the outlet is removed. The kaolin from the drier was carried by an elevator and conveyer to stock bins adjoining the drier, and from these bins the material was loaded into wagons and hauled 1 mile to the railroad.

The material produced by the principal dike worked on this property was sampled and was subsequently washed by the standard laboratory process. It yielded 40 per cent of kaolin. The material was selected with care and has been accepted as the standard of color value in the classification of kaolins in this district. The analysis of the material is given on page 45, under the color classification of the kaolin. Its refractory value is above 1,730° C., and its color is grade 1. Dried at 110° C. it shrinks 4 per cent, and fired at 1,350° C. it shrinks 11 per cent. The tensile strength is 25 pounds per square inch.

Properties in the standard porcelain mixture.

In the mixture and fired at 1,350° C. this kaolin has a translucency of 0.93 and the transmitted light is white. Absorption is 7 per cent. The color is grade 1. The shrinkage when dried at 1,350° C. is 3.4 per cent, and when fired at 1,350° C. is 9.9 per cent. Tested under the raw-lead and fritted glazes the color remains unaltered.

FRANKLIN. WEST PROSPECT.

This prospect (19) is one-half mile southeast of West Mills and 1 mile north of the Franklin-West Mills road, 8 miles north of Franklin, Macon County, N. C., on the Little Tennessee River.

The dike is approximately 25 feet wide, strikes west, and dips 80° S. Two tunnels run 40 feet into the hill, one 25 feet below the crest of the hill and the other 20 feet below the first. A large part of this dike is not completely kaolinized and carries considerable quartz. Numerous small streaks of stained material similar to the decomposed country rock run through the deposit at various angles. The tunnels in the West prospect are on the east slope of the ridge. On the opposite slope in the Bryson prospect a tunnel 120 feet long and 75 feet below the crest of the hill cuts material which is undoubtedly a part of the same dike, but which strikes northwest. Its dip is practically perpendicular. The kaolin exposed in this tunnel is remarkably clean and free from impurities.

The kaolin exposed on the West prospect was carefully sampled and washed, yielding 29 per cent kaolin. This kaolin was analyzed and showed the following chemical composition:

Composition of kaolin.

H_2O	12.70
SiO_2	48.92
Al_2O_3	36.37
Fe_2O_3	.37
TiO_2	.02
CaO	Trace.
MgO	Trace.
Na_2O	.11
K_2O	.29
	98.78

This kaolin has a refractory value of 1,730° C. Its color when fired to 1,350° C. is grade 3. Its shrinkage on drying at 110° is 7 per cent, and the total shrinkage at 1,350° C., 18 per cent. When dried at 110° this kaolin has a tensile strength of 24 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture fired at 1,350° C. this kaolin has a translucency of 0.66 and the transmitted light is cream colored. Absorption is 4.3 per cent. The color is grade 3. The shrinkage when dried at 110° is 3.6 per cent and fired at 1,350° C. is 14.2 per cent. When tested under the fritted and raw-lead glazes this kaolin shows a pale-green tint, equally apparent under either glaze.

LINCOLNTON. PIEDMONT TIN MINING CO. MINES.

These mines are 2½ miles southeast of Lincolnton, Lincoln County, N.C. There are four distinct dikes of more or less kaolinized pegmatite. These dikes, which strike N. 20° E., contain numerous narrow bands of yellow sand and of gold-colored clay. One dike known as the "Jake vein" is fairly free from stain and possibly contains some good commercial kaolin. These mines have been worked entirely by tunnels, and the dikes have been thoroughly prospected in the same way. The water encountered is diverted to a central point, collected in a pit, and pumped to the surface; in this way the entire dike is drained. The degree of kaolinization of these dikes seems to increase toward the southwest end, and even through the dikes carrying considerable stained material it is likely that kaolin production could be made profitable inasmuch as this kaolin is a by-product in mining cassiterite.

Material from the "Jake vein" was sampled and washed. It shows a kaolin content of 26 per cent. The washed product has a chemical composition as follows:

Composition of kaolin.

H_2O	12.00
SiO_2	48.50
Al_2O_3	37.35
Fe_2O_3	.85
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
Na_2O	.32
K_2O	1.02
	100.04

This kaolin has a refractory value of 1,710° C. Its color is grade 5. Its shrinkage is 4.4 per cent when dried at 110° C., and fired at 1,350° C. 8.1 per cent. The tensile strength when dried at 110° is 16.5 pounds per square inch.

Properties in standard porcelain mixture.

When introduced into the mixture fired at 1,350° C. this kaolin gives a translucency of 0.78 and the transmitted light is yellow. Absorption is 3.5 per cent. The color is grade 5. When dried at 110° this mass shrinks 2.2 per cent., at 1,350° 13 per cent. Tested under the fritted and raw-lead glazes the tint is unaltered.

MICAVILLE. THOMAS PROSPECT.

This prospect (73) is 1 mile north of Micaville, Yancey County, N. C., which is the nearest shipping point. The pegmatite dike is on a very narrow ridge and exposed in such a manner that its width can not be determined from present openings. It strikes N. 45° E. A tunnel 3 feet wide has been driven directly on the strike and a small shaft 40 feet deep has been sunk at the end of this tunnel. In both good kaolin is exposed. At a short distance to the northeast, on a ridge to which this dike is supposed to extend, the material is of good color but contains a proportion of sand. This high sand content is observed in the shallow pit which exposes the dike at the ridge. Various test holes have been dug on this property, but it is not possible to state accurately the width of any of the dikes exposed.

MICAVILLE. WILSON PROSPECT.

This prospect (78) is one-half mile southeast of Micaville, Yancey County, N. C. The dike follows the south and east face of a ridge and varies in width from 30 to 100 feet. It also appears on the west slope of the ridge in several tunnels (77). The pegmatite seems to be well kaolinized, but contains many narrow bands of yellow sand and clay which, however, can doubtless be removed without serious injury to the dike material. This prospect has been proven for about 700 feet by numerous shafts and tunnels and appears to be of uniform quality wherever exposed.

A tunnel midway between the limits of this dike was carefully sampled. The sample when washed yielded 28 per cent of kaolin. This kaolin has a refractory value above 1,730° C. and its color is grade 2. Dried at 110° C. it shrinks 4.2 per cent and fired at 1,350° C. it shrinks 13.2 per cent. It has a tensile strength of 24 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.72 and the transmitted light is cream colored. Absorption is 4.3 per cent. The color is grade 2. The shrinkage dried at 110° C. is 3.2 per cent and fired at 1,350° C. 13.6 per cent. Tested under the fritted and raw-lead glazes this kaolin shows a very pale-green tint, equally apparent under each glaze.

PENLAND. HARRIS CLAY CO. PENLAND MINE.

This mine (98) is on the north side of North Toe River, on a high ridge having a general north trend, and is one-fourth mile east of Penland, Mitchell County, N. C.

The deposit is in the form of an expanded lens 120 to 160 feet wide. It strikes N. 25° E. The pegmatite is very fine grained and has a texture not unlike granite, the kaolinization of a considerable part of the dike not being sufficient to destroy the texture of the original rock. The southeast wall is well defined, but the northwest wall is hardly distinguishable, as the dike material on that side grades gradually into a hard, granitelike rock producing little or no kaolin. The west part of the dike contains numerous irregular streaks of iron-stained material. The mine has been opened for about 400 feet along the strike and for a depth of about 50 feet, below which the kaolin yield is too small to justify mining. About 50 yards beyond the southeast wall of this deposit a dike approximately 10 feet in width and very rich in kaolin has been exposed, but has never been developed.

The dike now being worked was sampled. Washed by the standard laboratory process the sample yielded 22 per cent of kaolin. This kaolin has a refractory value of 1,730° C. Fired at 1,350° C. its color is grade 4. Its shrinkage when dried at 110° C. is 3.4 per cent, and when fired at 1,350° C. is 11.6 per cent. The tensile strength of the kaolin dried at 110° C. is 12 pounds per square inch.

Properties in standard porcelain mixture.

This kaolin introduced in the mixture and fired at 1,350° C. has a translucency of 0.62. The transmitted light is cream colored. Absorption is 5 per cent and color is grade 4. Dried at 110° C. this mass shrinks 3.2 per cent, and when fired at 1,350° C. shrinks 13 per cent. Tested under the raw-lead and fritted glazes the color of this mixture becomes a pale green, equally apparent under each glaze.

RUTHERFORDTON. ISINGLASS HILL MICA MINE.

This mine is 3 miles north of Rutherfordton in Rutherford County, N. C., on the Southern Railway. There is no railroad switch or station nearer than Rutherfordton. This dike varies from 6 to 50 feet wide and is proven for one-fourth mile along the crest of a low ridge. It strikes N. 20° E. and dips 80° W. The dike rock is pegmatite in various stages of kaolinization. The material adjoining the west wall is generally more thoroughly kaolinized than that in the eastern part, the dike being divided in the middle by a band of sugar quartz from 1 to 3 feet wide. The kaolinized pegmatite contains but little fine quartz, but this is smoky quartz in sharp elongated particles. In various parts of the weathered dike are nodules of asbolite, but little or none is found in the band of sugar quartz. This mine has been opened to a depth of only about 20 feet by both shafts and tunnels, the dike structure remaining very uniformly as above described.

The kaolinized half of the dike was sampled and by the laboratory washing process yielded 42 per cent of kaolin, which has a refractory value of 1,730° C. The color of this washed kaolin is grade 5. When dried at 110° it has a shrinkage of 2.8 per cent, and when fired at 1,350° C., 11.3 per cent. The tensile strength when dried at 110° is 8 pounds per square inch.

Properties in standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin shows a translucency of 0.64 and the transmitted light is cream colored. Absorption is 8.8 per cent. The color of the mass when fired is grade 3, as compared with grade 5 for this kaolin burned alone. When dried at 110° the mass shrinks 2.2 per cent, and when fired at 1,350° C. it shrinks 12.4 per cent. Tested under the raw-lead and fritted glazes the color is unaltered.

SHELBY. TOM BAXTER MICA MINE.

This mine is in Lincoln County, N. C., 12 miles northeast of Shelby and 3 miles southeast of Fallston on the Fallston-Lincolnton road. The nearest shipping point is Waco, 4 miles distant.

The mine has not been worked for several years and the exposure conveys little information as to the extent of the dike. The area in which shafts have been sunk is about 40 feet long, although there are indications of a continuation of the dike in the adjoining fields for 100 feet or more in both directions. The width of the dike is reported to be almost 100 feet. The general direction of the strike is N. 50° to 70° E. Only at one point was it possible to observe the kaolin in place, but the dumps from the mica workings carry considerable very fine kaolin, indicating that there must be some in the deposit. Workmen who were employed in mining mica state that at about 30 feet they found kaolin practically free from quartz and in one shaft reached a depth of 47 feet, but the dike material was so soft and caved so badly that the mine was abandoned. Water was struck at about 35 feet, and the difficulty of removing it with the crude facilities provided also discouraged the attempt to mine mica.

The one point at which the dike is exposed was carefully sampled. Washed by the laboratory washing process the sample yielded 49 per cent of kaolin, which has a refractory value above 1,730° C. and a color of grade 2. This kaolin dried at 110° shrinks 4.4 per cent and fired at 1,350° C. it shrinks 12.2 per cent. Its tensile strength when dried at 110° C. is 8 pounds per square inch.

Properties in standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin shows a translucency of 0.73 and the transmitted light is cream colored. Absorption is 8.1 per cent. The color of the mass is grade 2. The shrinkage is 1.6 per cent when dried at 110° C. and 10.8 per cent when fired at 1,350° C. Tested under the raw-lead and fritted glazes this mass is unaffected in tint.

SHELBY. GREEN MICA MINE.

This mine is 7 miles northwest of Shelby, Cleveland County, N. C. It was worked for mica about 1870 and again worked in a small way a few years later. The openings were all shafts; these are now completely caved, making satisfactory sampling impossible. The dike, as nearly as could be determined, is about 12 feet thick with numerous stringers running nearly parallel. The strike is about N. 70° E. and the dip approximately 75° W. Bands of sugar quartz from 2 to 4 feet thick occur along the hanging wall. In places the dike material is almost completely kaolinized, and it is reported in the neighborhood that much excellent kaolin was exposed in the shafts. The present exposures, however, are so small and so badly stained from infiltration of surface water that an estimate of the quality or quantity of kaolin available is not attempted.

SPRUCEPINE. HARRIS CLAY CO. SPRUCEPINE MINE.

This mine (96) is 2½ miles north of Sprucepine, Mitchell County, N. C., and on the east side of Beaver Creek.

The vast lens or thick dike of kaolinized pegmatite has an irregular structure. Its general trend is northwest. Where worked the dike is about 120 feet wide but the northeast part for a width of 50 to 70 feet is much richer in kaolin than the southwest. An additional stringer has been located 25 feet east of the lens since the study of this deposit began, having a width of about 20 feet and a general direction north. The material in this small lens or stringer is similar in every way to that of the eastern part of the mine. The pegmatite of the dike is well kaolinized, but its quartz content is very high. The mine has been worked by open cut to a depth of about 20 feet and by shaft to an additional depth of 55 feet, below which the kaolinization of the pegmatite has not advanced far enough to make mining profitable. The dike material is removed from the shafts by steam hoists and piled in heaps at the level of the open-cut. From this point it is shoveled into a flume, the water for which comes from a small mountain stream above the mine, and is flushed one-fourth mile to the washing plant. This plant has two batteries, each consisting of a washer and sand wheel, and from them the material passes to a sand trough and thence to the mica-settling trough. From the latter the clay slip passes through 100-mesh screens into a flume which carries it 2½ miles to the railroad, where the settling and drying plant is located. Here the slip is passed over a second battery of screens to remove any material caught in transit and goes to the settling tanks through a trough in which are suspended bags containing alum to aid concentration. From the settling tanks the concentrated material is removed to agitators and pumped into filter presses, of which this plant has two.

The kaolin from the filter presses goes to either the open-air or the steam drier. The latter is a long building having a floor covered with steam pipes on which the pressed kaolin is piled directly. The steam pipes are closed at one end, whereas in most of the steam drying plants throughout this district the pipes are open at one end and the steam is allowed to escape into the air.

The open-air drier is unique in that it has a removable roof. The kaolin is piled on a simple system of racks, but the roof, which is of the ridge type, is constructed independently of the framework of the building, and rests on a track. When the weather is favorable it can be rolled off entirely, allowing the sun to shine directly on the drying material.

The washing removes a large proportion of fine white mica, the yield of this material being estimated as 8 to 12 per cent of the kaolin produced. From 30 to 40 per cent of the mica separated is finer than 100 mesh and should be directly marketable as pulverized mica.

The deposit was sampled as well as possible to obtain an average of the entire area exposed; it yielded 24 per cent of washed kaolin. This kaolin was analyzed and found to have the following chemical composition:

Composition of kaolin.

H_2O	14.80
SiO_2	45.20
Al_2O_3	38.45
Fe_2O_3	.45
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
Na_2O	.00
K_2O	.65
	99.55

The refractory value of this kaolin is above 1,730° C. and the color grade 3. The shrinkage of the kaolin dried at 110° C. is 4 per cent and fired at 1,350° C. is 12.6 per cent. The tensile strength is 8 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture fired at 1,350° C. the translucency is 0.67 and the transmitted light is cream colored. Absorption is 4.2 per cent. The color is grade 3; the shrinkage is 3.8 per cent when dried at 110° C. and 12.6 per cent fired at 1,350° C. Tested under the raw-lead and fritted glazes the kaolin showed a very pale green tint, equally apparent under both glazes.

SPRUCEPINE. OLLIS PROSPECT.

This prospect (105) is 6 miles northeast of Sprucepine, Mitchell County, N. C., and 1 mile east of the Sprucepine-Plumtree road. There is a pegmatite dike exposed as a broad lens along a ridge proven for a length of 250 yards and in places for a width of 100 feet. The strike is west, the dip 80° S. This dike is exposed by numerous shafts and tunnels and was carefully sampled and washed by the laboratory washing process, yielding 36 per cent of kaolin.

The kaolin content has a refractory value above 1,730° C. Its color is grade 5. Its shrinkage when dried at 110° is 4.6 per cent and fired at 1,350° is 9.6 per cent. The tensile strength of the kaolin dried at 110° is 17 pounds per square inch.

Properties in standard porcelain mixture.

Tested in the mixture and fired at 1,350° C. this kaolin has a translucency of 0.68 and the transmitted light is yellow. Absorption is 3.6 per cent. The color is grade 5. The shrinkage at 110° is 3.6 per cent and at 1,350° C. 12.2 per cent. Tested under the fritted and raw-lead glazes the tint of the mass is unaltered.

SPRUCEPINE. TOLLEY MICA MINE.

This mine (99) is 1 mile southwest of Sprucepine, Mitchell County, N. C., on the Sprucepine-Burnsville road. The dike is exposed to a width of about 25 feet and from surface indications is approximately 10 feet wider. The material in the dike seems to be very uniform, no bands of wall rock being noted. Numerous stringers from this dike are exposed where it crosses the road 50 yards distant. This dike has been proven for 300 feet and is opened by a shaft claimed to have been originally 45 feet but now only 20 feet deep, and by a drift from this shaft at the 20-foot level. The drift runs 25 feet north, then turns and extends 7 feet to the west. The dike material in this dike seems very white but very sandy. The sample collected, when washed by the laboratory process, yielded 30 per cent kaolin.

This has a chemical composition as follows:

Composition of kaolin.

H_2O	14.00
SiO_2	46.35
Al_2O_3	38.80
Fe_2O_3	.25
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
BaO	.03
Na_2O	Trace.
K_2O	.41
	99.84

This kaolin has a refractory value above 1,730° C. Its color is grade 2. Dried at 110° C. it has a shrinkage of 5.4 per cent and fired at 1,350° C. shrinks 10.9 per cent. Dried at 110° C. the kaolin has a tensile strength of 8 pounds per square inch.

Properties in standard porcelain mixture.

This kaolin introduced into the mixture and fired at 1,350° C. has a translucency of 0.71 and the transmitted light is cream colored. Absorption is 7.3 per cent. Its color is grade 2. The mass when dried at 110° C. has a shrinkage of 3.4 per cent and when fired at 1,350° C. 14 per cent. Tested under the fritted and raw-lead glazes this mass acquires a very pale green tint, equally apparent under each glaze.

SPRUCEPINE. WISEMAN PROSPECT.

This prospect (104) is on Fort Creek, a branch of Three-Mile Creek, 3 miles north of Ingalls post office and 8 miles north of Sprucepine, Mitchell County, N. C.

The dike is ruptured by numerous intrusions, which at some points are stringers only a few feet wide; at others, form a single dike about 20 feet wide. The dike strikes N. 40° E. It varies in degree of kaolinization, but is remarkably free from impurities and is also very low in quartz. The workings consist of tunnels and shafts opened to expose the kaolin.

All the exposed material of the main dike was sampled. Washed by the laboratory process, the sample averaged 37 per cent of kaolin. This kaolin has a refractory value above 1,730° C. The color when fired at 1,350° C. is grade 1. Dried at 110° C. this kaolin shrinks 7.4 per cent and fired at 1,350° C. it shrinks 17.4 per cent. It has a tensile strength of 17.5 pounds per square inch.

Properties in standard porcelain mixture.

This kaolin when introduced into the mixture and fired at 1,350° C. gives a translucency of 0.72. The transmitted light is cream colored. Absorption is 8.3 per cent. The color is grade 1. The kaolin, dried at 110° C., shrinks 4.4 per cent; when fired at 1,350° C., shrinks 14.4 per cent. The color is unaffected by the application of either the raw-lead or fritted glazes.

SPRUCEPINE. WISEMAN PROSPECT.

This prospect (101) is on the Marion road, 3 miles southeast of Sprucepine, Mitchell County, N. C. The pegmatite dike, which is more or less kaolinized, has a northeast strike and a nearly vertical dip. The half adjoining the southeast wall is incompletely kaolinized, but kaolinization of the northwest half is well advanced. The entire deposit, however, is very sandy, as is common among kaolin deposits in this immediate vicinity. Adjoining this dike on the southeast side is a narrow ledge of coarse granite-pegmatite which is apparently unaltered.

The kaolinized portion of this dike was sampled and tested with the following result:

In the laboratory washing process it yielded 21 per cent of kaolin. The refractory value of the kaolin is 1,730° C. The color is grade 2.

The shrinkage is 3.2 per cent when dried at 110°, and 11.9 per cent when fired at 1,350° C. When dried at 110° C. this kaolin has a tensile strength of 17 pounds per square inch.

Properties in standard porcelain mixture.

Tested in the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.76 and the transmitted light is cream colored. Absorption is 3.7 per cent. The color is grade 2. The shrinkage when dried at 110° is 3.8 per cent, and when fired at 1,350° C., 13 per cent. The color under the fritted and raw-lead glazes is unaltered.

SYLVA. BUCHANAN PROSPECT.

This prospect (52) is 1½ miles east of Sylva and one-half mile south of the Murphy Branch of the Southern Railway in Jackson County, N. C.

The dikes exposed vary in width from 10 to 18 feet, strike N. 40° E. and dip 80° N. One dike is exposed on or along a ridge that trends north. The overburden at the higher points averages from 2 to 10 feet, but downhill it averages from 15 to 20 feet. The dike at the higher elevation is exposed along the ridge and is one-eighth mile east of the other dike, hence the two are undoubtedly not a continuation of the same dike although very similar as regards appearance and associated materials. In all of these dikes small lenses of garnet-colored sand mixed with altered biotite are found, but their removal under ordinary mining conditions would not cause any difficulty. The higher dike has been opened only by shallow pits, and the quality of the kaolin exposed is doubtless inferior to that obtainable at a little greater depth. The lower dike is well exposed by shafts 25 feet deep and by two tunnels and is of quite uniform structure and width.

The lower dike was carefully sampled. Washed by the standard laboratory method the sample yielded 40 per cent of kaolin. This kaolin has a chemical composition as follows:

Composition of kaolin.

H_2O	13.77
SiO_2	46.30
Al_2O_3	39.06
Fe_2O_3	.20
TiO_2	.04
CaO	Trace.
MgO	Trace.
Na_2O	.11
K_2O	.60
	100.08

This kaolin has a refractory value above 1,730° C. Its color is grade 3. Its shrinkage when dried at 110° is 5.4 per cent, and its total shrinkage at 1,350° C., 13.9 per cent. The tensile strength of this kaolin when dried at 110° is 28.5 pounds per square inch.

Properties in standard porcelain mixture.

This kaolin when introduced into the mixture and fired at 1,350° C. gives a translucency of 0.64 and the transmitted light is cream colored. Absorption is 5.3 per cent. The color is grade 3. The shrinkage of the mass dried at 110° is 3 per cent; fired at 1,350° C., 13.1 per cent. Tested under the fritted and raw-lead glazes the mixture shows a pale-green tint, which is equally apparent under each glaze.

SYLVA. FOREST HILL MICA MINE.

This mine (62) is on the Cox property 10 miles south of Sylva and 1 mile west of Cullowhee Creek in Jackson County, N. C.

The dike has a general northeast strike and a vertical dip. It varies from 8 to 20 feet wide, and a number of stringers of great thickness are visible in the immediate neighborhood. Another dike (65) is exposed by a shallow pit 100 yards to the north of this main dike but 50 feet below. An exposure of kaolin is also seen 1 mile south (66). The dike is in various stages of kaolinization, but is uniformly very free from impurities with the exception of a little quartz; no wide quartz bands were exposed by any of the numerous tunnels that have been driven in search of mica.

The kaolin material was sampled by the laboratory washing process; it shows a kaolin content of 31 per cent. This kaolin has a chemical composition as follows:

Composition of kaolin.

H_2O	12.53
SiO_2	49.20
Al_2O_3	37.58
Fe_2O_3	.17
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
Na_2O	.13
K_2O	.47
	100.08

This kaolin has a refractory value of 1,730° C. Its color when fired at 1,350° C. is grade 2. The shrinkage in drying at 110° is 4 per cent, and when fired at 1,350° C., 9.7 per cent. When dried at 110° this kaolin has a tensile strength of 16 pounds per square inch.

Properties in standard porcelain mixture.

In this mixture when fired at 1,350° C. the kaolin has a translucency of 0.73 and the transmitted light is cream colored. Absorption is 5.5 per cent. The color is grade 3. Dried at 110° C. the kaolin shrinks 1.4 per cent, and fired at 1,350° C., 11.6 per cent. When the fritted glaze or the raw-lead glaze is applied to this mixture the mass assumes a very pale green tint.

SYLVA. NORTH CAROLINA MINING & MANUFACTURING CO. MINE.

This mine (54, 55) is 2 miles south of Sylva, Jackson County, N. C., on the south slope of a mountain. The kaolinized pegmatite dike varies from 8 to 18 feet in width and strikes N. 45° E. There is a surface cut of about 200 feet, about 20 feet deep. From this level shafts have been sunk and material below has been removed. These shafts have been filled and their depth could not be determined, the surface indications only proving their existence. This mine is mentioned in Bulletin No. 13 of the North Carolina Geological Survey, which refers to numerous patches of partly kaolinized material in the dike, and states that several tons of fresh feldspar are reported to have been shipped.

At only one point is the dike material now exposed. This material was sampled and washed and found to contain 26 per cent of kaolin. The analysis of this kaolin as given by the North Carolina Geological Survey is as follows:

Composition of kaolin.

Moisture	3.07
SiO_2	44.08
Al_2O_3	36.26
Fe_2O_3	1.86
CaO	.43
MgO	.20
KNaO	.50
Combined water	13.56
	99.96

The general run of kaolin taken from this mine and washed by the standard laboratory process is doubtless much lower in iron than is indicated by this analysis since the refractory value is above 1,730° C. and the color is grade 2. Dried at 110° C. it shrinks 5.7 per cent and fired at 1,350° C. 12.6 per cent. The tensile strength is 18 pounds per square inch.

Properties in standard porcelain mixture.

In this mixture fired at 1,350° C. the kaolin gives a translucency of 0.66 and the transmitted light is cream colored. Absorption is 6.1 per cent. The color is grade 2, and the shrinkage is 3.2 per cent dried at 110° C. and 13.3 per cent when fired at 1,350° C. Tested under the raw-lead and fritted glazes it shows a pale-green tint, equally apparent under each glaze.

SYLVA. RODA KAOLIN AND MICA MINE.

This mine (67) is 7 miles southeast of Sylva, Jackson County, N. C., on the south side of the Tuckasegee River opposite the mouth of Cany Fork. The pegmatite dike cuts diagonally a low ridge and has a general northeast strike. A broad band of sugar quartz follows the south wall, which is very crooked. The extent of the dike has been proven more or less by test pits, but the chief exposure is by a long tunnel driven from the west slope of the hill. This tunnel passes through a broad band of low-grade pegmatite material into a band having a low quartz content. At this point a deep shaft has been sunk from the tunnel across its entire width and the portion of the tunnel beyond this point was inaccessible.

The material in the neighborhood of the shaft, consisting of equal portions of the material rich in kaolin and material lean in kaolin, was sampled. Washed by the standard laboratory process the sample contained 26 per cent of kaolin. This kaolin has a refractory value above 1,730° C. Its color is grade 2. Its shrinkage dried at 110° C. is 4.1 per cent and fired at 1,350° C. is 12.7 per cent. The tensile strength is 21 pounds per square inch.

Properties in the standard porcelain mixture.

Introduced into the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.66 and the transmitted light is cream-white. Absorption is 5.7 per cent. The color is grade 2. Dried at 110° C. the shrinkage is 3 per cent and fired at 1,350° C. is 12.2 per cent. Tested under the raw-lead and fritted glazes it shows a very pale green, equally apparent under both glazes.

TOECANE. P. H. HOWELL PROSPECT.

This prospect (80) is 3 miles southeast of Toecane, Mitchell County, N. C., and 1 mile southwest of the forks of Sink Hole road running to Youngs Siding. The dike is on a high ridge along the crest and the general direction of the strike is N. 45° E. The dip is 80° NW. The width varies greatly, different exposures indicating a thickness of from 8 to 18 feet. The kaolinization of the pegmatite is well advanced, but the dike still contains some scattered semikaolinized lenses (79). The wall rock is a brown gneiss which differs distinctly in color from the Roan gneiss, which is the ordinary country rock throughout this district.

The dike was sampled across its entire width. Washed by the standard laboratory process the sample yielded 31 per cent of kaolin. The refractory value of this kaolin is 1,710° C. Its color is grade 2. Dried at 110° C. it shrinks 3 per cent; fired at 1,350° C. it shrinks 12.7 per cent. The tensile strength is 17 pounds per square inch.

Properties in standard porcelain mixture.

In the mixture and fired at 1,350° C. this kaolin has a translucency of 0.69 and the transmitted light is cream colored. Absorption is 5.9 per cent. The color is grade 2. The shrinkage dried at 110° C. is 3.4 per cent and fired at 1,350° C. is 13.1 per cent. Tested under the raw-lead and fritted glazes the mass shows a very pale green tint, equally apparent under each glaze.

WAYNESVILLE. KINSLAND MINE.

This mine is on the Crabtree road, 9 miles northeast of Waynesville, Haywood County, N. C., just beyond the bridge over Pigeon River.

The broad dike is divided into many sections by intruded material, but totals 75 feet in width. In one place where exposed by an old road the general outline of the lenses of harder pegmatite and of wall rock are easily seen. The bands of kaolin material average from 6 to 8 feet wide and generally have a very high quartz content; the quartz is not in solid bands but is scattered through the mass as small angular particles from one-eighth to one-half inch in size. The dike is opened by a number of shafts and tunnels, but most of them have caved badly. One of them still exposes the dike at a depth of about 20 feet where the kaolin, as in the road exposure, shows a rather excessive quartz content. This dike has a general strike N. 40° E. In addition to the exposures already mentioned there is an outcrop on the strike of this dike on a low hill 300 yards distant which shows the same general structure as this deposit.

The kaolin in the shaft was carefully sampled. Washed by means of the laboratory apparatus this sample contained 27 per cent of kaolin. This kaolin was analyzed; it has the following chemical composition:

Composition of kaolin.

H_2O	11.90
SiO_2	50.64
Al_2O_3	35.57
Fe_2O_3	.25
TiO_2	.03
CaO	Trace.
MgO	Trace.
BaO	.07
Na_2O	.08
K_2O	1.70
	100.24

This kaolin has a refractory value of 1,670° C. Its color is grade 5. Its shrinkage at 110° C. is 4.4 per cent. Its shrinkage when fired at 1,350° C. is 9.8 per cent. Its tensile strength when dried at 110° is 8 pounds per square inch.

Properties in standard porcelain mixture.

Fired at 1,350° C. this kaolin in the mixture has a translucency of 0.76 and the transmitted light is cream colored. Absorption is 2.6 per cent. The color is grade 5. Dried at 110° the kaolin shrinks 1 per cent; fired at 1,350° C. it shrinks 13.6 per cent. Tested under the fritted and raw-lead glazes this porcelain mass remains unchanged in tint.

WEBSTER. COWAN PROSPECT.

This prospect is one-half mile southeast of Webster, Jackson County, N. C., just west of the nickel-refining plant at that place. The test hole where the kaolinized material is exposed is near a small branch and the exposure is so small that no idea can be formed of the extent of the dike. The quality of the material, however, is high. No indications of kaolin or of pegmatite dikes are noted on the surface in the neighborhood of this exposure, but the overburden on the hillside is thick enough to hide them.

WEBSTER. HALL MINE.

This mine (57) is directly west of Webster, Jackson County, N. C., on a low ridge above Tuckasegee River and midway between Harris Bridge and Webster Bridge.

The dike has several stringers which vary from 10 to 20 feet in width. It strikes N. 40° E., the dip being almost vertical. It is opened by a tunnel 60 feet long, which follows the strike, and a shaft about 20 feet deep. The shaft, however, has fallen in badly, so that samples could not be taken. The tunnel was sampled across the full width of the dike. The sample when washed yielded 24 per cent of kaolin. The refractory value of the kaolin is above 1,730° C. Its color is grade 4. Dried at 110° C. it shrinks 4.9 per cent, and fired at 1,350° C. it shrinks 12.4 per cent. The tensile strength is 18 pounds per square inch.

Properties in standard porcelain mixture.

In this mixture fired at 1,350° C. the kaolin has a translucency of 0.68 and the transmitted light is cream colored. Absorption is 4.6 per cent. The color is grade 4. The shrinkage of the kaolin dried at 110° C. is 3.1 per cent and fired at 1,350° C. is 13 per cent. Tested under the raw-lead and fritted glazes the color remains unaltered.

WEBSTER. LONG MICA MINE.

This mine (61) is one-fourth mile northeast of the mouth of Wayehutta Creek and 4 miles southeast of Webster, Jackson County, N. C.

The irregular pegmatite dike strikes N. 70° E. Mining has been entirely for mica and two tunnels have been run into the hill, only one having been opened at the time of the visit. An open-cut directly above this tunnel exposes the surface of the dike. The width of this dike varies from 10 to 20 feet and is considerably broken by intrusions of wall rock. The dike is well advanced in kaolinization but contains considerable streaked material similar to infiltrated surface stain.

The richer part of the dike was sampled, care being taken to obtain material free from stain. The sample washed by the standard laboratory process yielded 35 per cent of kaolin. The refractory value of this kaolin is above 1,730° C. Its color is grade 2. Its shrinkage when dried at 110° C. is 4.1 per cent and fired at 1,350° C. 11.2 per cent. The tensile strength is 20 pounds per square inch.

Properties in standard porcelain mixture.

In this mixture fired at 1,350° C. the kaolin has a translucency of 0.69 and the transmitted light is cream colored. Absorption is 6 per cent. The color is grade 2. The skrinkage when dried at 110° C. is 3 per cent and fired at 1,350° C. 13.8 per cent. Tested under the raw-lead and fritted glazes the kaolin shows a very pale green tint, equally apparent under each glaze.

WILLETTS STATION. WAYEHUTTA MICA MINE.

This mine (56) is on the west face of Black Mountain near the head of Wayehutta Creek and 3 miles south of Willetts Station, Jackson County, N. C.

The irregular pegmatite dike strikes N. 70° E. and has a varying dip. The dike where exposed seems to be about 50 feet wide with a 10-foot horse of the wall rock near the center. A massive quartz band occurs along the south wall. The openings are four tunnels, only one of which penetrates kaolin material in commercial quantity. These tunnels are all on the steep slope of the ridge 300 feet or more above the road and 40 to 60 feet below its crest.

The kaolin material was sampled. Washed by the standard laboratory method the sample yielded 33 per cent of kaolin. This kaolin has a refractory value above 1,730° C. Its color is grade 2. Dried at 110° C. it shrinks 4.6 per cent, and fired at 1,350° it shrinks 12.3 per cent. The tensile strength of the kaolin dried at 110° is 12.5 pounds per square inch.

Properties in standard porcelain mixture.

When tested in the mixture fired at 1,350° C. this kaolin has a translucency of 0.64 and the transmitted light is cream colored. Absorption is 7.1 per cent. The color of the porcelain mixture is grade 2. The shrinkage at 110° is 3.6 per cent and when fired at 1,350° C. 12.6 per cent. When tested under the fritted and raw-lead glazes no change of tint is noticeable.

VIRGINIA.

LYNCHBURG. RADFORD PROSPECT.

This prospect is 1¼ miles northeast of Forest Depot, Bedford County, Va., and 10 miles southwest of Lynchburg.

The pegmatite dike varies from 6 to 15 feet wide and is reported to have been proven for nearly 500 feet by auger borings. For 300 yards along the strike of this dike a narrow band of semikaolinized material is apparent. The strike of the dike is N. 30° E. It is opened by a pit 35 feet deep and contains a 12-inch flint band near the middle. The dike structure is variable, showing bands of soft kaolin comparatively free from sand and mica and also many bands containing 0.1 per cent of sand and small mica, as well as much semikaolinized material. In this shaft was noted a streak of garnet sand similar to streaks in North Carolina dikes. The overburden in few places exceeds 6 to 8 feet and the prospect is for the most part on an elevated tract of land one-half mile from Wolfe Creek and is crossed by Double Branch, a tributary of Wolfe Creek.

The kaolinized part of this dike was sampled. Washed by the standard laboratory process the sample yielded 27 per cent of kaolin having a refractory value above 1,710° C. The color is grade 4. The shrinkage of the kaolin dried at 110° C. is 6.2 per cent, and fired at 1,350° C. is 16.4 per cent. The tensile strength of the kaolin dried at 110° is 17 pounds per square inch.

Properties in standard porcelain mixture.

When introduced into the mixture and fired at 1,350° C. this kaolin gives a translucency of 0.69 and the transmitted light is yellow. Absorption is 5.1 per cent. The color is grade 4. When dried at 110° C. the shrinkage is 5.4 per cent, and when fired at 1,350° C. is 15 per cent. Tested under the raw-lead and fritted glazes this mass shows a very pale green tint, equally apparent under each glaze.

HENRY. BLUE RIDGE MINE.

This mine is 3½ miles southeast of Henry, Henry County, Va., on a ridge 100 feet above the creek. There is either a series of separate dikes of no great width or perhaps one broad dike with numerous bands of foreign material. The majority of the kaolinized pegmatite bands now exposed are not more than 3 to 8 feet wide, and most of the associated bands of foreign material are gray sand carrying little or no kaolin. The area that has been worked over covers about 10 acres, and a few of the shafts have been sunk about 80 feet. There are small lenses of garnet sand and iron-stained blocks of mica, large and small, which necessitate careful hand picking in order to make a marketable kaolin. The mine has been abandoned several years, and the washing plant is dismantled. Whether additional kaolin still remains on this property in commercial quantities could not be determined.

ASSOCIATED MINERALS IN THE PEGMATITE DIKES.

OCHER.

AQUONE, N. C. YONCE FARM PROSPECT.

Ocher is found on the Yonce farm (16) 2 miles north of Aquone on Nantahala River, in Macon County, N. C.

A deposit of this material is exposed in a creek bed for a width of about 15 feet. The dike strikes N. 35° E., and consists of four bands, of which a 4-foot band along the west wall and a 2-foot band along the east wall are very rich. The central portion of the dike is very sandy. No attempt has been made to develop this deposit, and no other exposures in either direction were found. A small deposit of similar material 100 yards east of this exposure is opened along a hillside, but from the associated material this is not believed to be the same body, although it may be a stringer from this body.

The richest parts of this deposit were sampled and washed and yielded 42.5 per cent of high-grade golden ocher having the following composition:

Composition of ocher.

Volatile matter	13.59
SiO_2	15.40
Al_2O_3	16.25
Fe_2O_3	51.00
TiO_2	.30
	96.54

Alkali and alkaline earths were not determined.

SPRUCEPINE, N. C. HARRIS CLAY CO. KAOLIN MINE.

This mine (96) is north of Sprucepine, Mitchell County, N. C. The part of this deposit immediately below the overburden is a golden color in many places for a depth of 5 to 8 feet.

This material was sampled and washed and found to contain 34 per cent of ocher. It contains much very fine mica, however, and must be washed with great care.

Practically all the kaolin deposits in the Mount Mitchell district display this yellow material near the surface, and it may be washed to form a marketable product having a value equal to that of the kaolin.

SCHROETTERITE.

DILLSBORO, N. C. HARRIS CLAY CO. KAOLIN MINE.

This mine (60) is 5 miles southeast of Dillsboro, Jackson County, N. C. Associated with the kaolinized pegmatite found in this dike is a material similar to semikaolinized feldspar in appearance, but widely different in composition.

This material occurs as small lenses or bands in the dike material and is reported as occurring at all levels, although its occurrence is noted oftenest at levels below 60 feet. Samples of this material show the following composition:

Composition of schroetterite.

H_2O	27.90
SiO_2	21.90
Al_2O_3	49.60
Fe_2O_3	.30
TiO_2	Trace.
CaO	Trace.
MgO	Trace.
K_2O	.10
Na_2O	.00
	99.80

The composition approaches that of the mineral schroetterite, the formula of which is: $Al_{16}Si_3O_{30}.30H_2O$. This substance has a formula $Al_{16}Si_3O_{30}.25.4H_2O$, and differs from schroetterite in the amount of combined water only.

SUGAR QUARTZ.

Sugar quartz is apparently of uniform quality wherever found, except that in some cases it is stained with infiltrated iron-bearing material or with incrustations of wad. If the quartz is to be used in the manufacture of pulverized flint that which is stained must be removed by hand.

Samples of sugar quartz from numerous mines and prospects have been tested. An analysis of this material is as follows:

Analysis of sugar quartz.

SiO_2	99.32
Al_2O_3	.49
Fe_2O_3	Trace.
H_2O and organic	.10
	99.91

Pulverized and fired this material is a white powder that shows no bonding strength when heated to 1,350° C.

Properties in standard porcelain mixture.

Introduced into the mixture this sugar quartz shows a translucency of 0.69 and has a pale-yellow tint. The color is grade 5. The shrinkage when dried at 110° C. is 3.2 per cent; fired at 1,350° C. it is 16 per cent. Under the raw-lead and fritted glazes the color is unaltered.

WAD.

In most of the kaolinized pegmatite dikes throughout the region investigated are nodules of wad scattered through the mass or incrusted in fissures in the quartz bands. Wad is an earthy manganese ore and carries some cobalt and other metal oxides. These nodules are found occasionally in the Gurney kaolin mines and are very abundant in the Isinglass Hill mica mine.

Wad is found in nearly all other dikes examined as crusts in the crevices of the ruptured quartz bands. Samples of this material have been taken and its identity established by determinative mineralogy methods.

In the kaolin mine of the Southern Clay Co., 1 mile northwest of Franklin, Macon County, N. C., a large amount of this material was found, which was sampled and analyzed. The chemical composition is as follows:

Composition of nodule of wad.

Volatile matter	15.30
SiO_2	33.20
Al_2O_3	24.60
Fe_2O_3	4.00
TiO_2	.25
Mn_3O_4	21.80
CaO+NiO	.75
CuO	.50
	100.40

PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls., 4 figs.

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BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice; with chapters by J. C. W. Frazer, Axel Larson, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

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Roaring
Powdermill
Creek
Spear
Spear
Tops
Bra
Mt.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

Bulletin 54

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

FOUNDRY-CUPOLA GASES AND TEMPERATURES

BY

A. W. BELDEN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

First edition. March, 1913.

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FOUNDRY-CUPOLA GASES AND TEMPERATURES.

By A. W. Belden.

INTRODUCTION.

Among the investigations that the Bureau of Mines is conducting with a view to increasing efficiency in the utilization of fuels belonging to or for the use of the Government is an investigation of the processes that take place in a foundry cupola during a melt.

Some observations on the results of cupola tests of cokes at the Government fuel-testing plant in St. Louis, Mo., the coke being from coal from many coal fields of the United States, have been stated in a previous bulletin.[a] Especial attention was given to the melting losses that resulted from the use of different grades of coke, light and porous or heavy and dense. These losses amounted in one instance to 52.5 per cent of the iron charged and showed, in convincing manner, the need of exact information in regard to conditions in the fuel bed of the cupola.[b]

Melting losses of iron have been fully appreciated but little understood. The fact that these losses were possible with either light or heavy coke led to the belief that by using small charges so placed that melting would take place in that zone of the cupola where the highest heat and the smallest percentage of oxygen prevailed and by confining all melting to this zone these losses would be eliminated and the economical use of practically any coke produced for metallurgical purposes would become possible. This widening of the field from which coke might be drawn for foundry purposes would serve to place the foundryman in an independent position as regards his source of supply, and would tend to conserve the better grades of coking coals, which are being rapidly exhausted, by making the poorer grades available for mixing with them.

In order to investigate conditions within a cupola, the Bureau of Mines as a first step decided to install a commercial cupola, to sample the gases during their travel from the tuyères upward, and to determine the temperature of the fuel bed.

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[a] Moldenke, Richard, The coke industry of the United States as related to the foundry: Bull. 3, Bureau of Mines, 1910, 34 pp.

[b] For description of the tests at St. Louis, see U. S. Geol. Survey Bull. 336.

ACKNOWLEDGMENTS.

Acknowledgment is made of the many courtesies and assistance extended by foundrymen generally, especially by Maj. J. S. Seaman and the Jamison Coal and Coke Co., of Pittsburgh, Pa., and Dr. Richard Moldenke, of Watchung, N. J., secretary of the American Foundrymen's Association. The author is greatly indebted to the personal assistance of his colaborers in the bureau, both chemists and engineers, who, since the beginning of the investigation in 1911, have made many valuable suggestions.

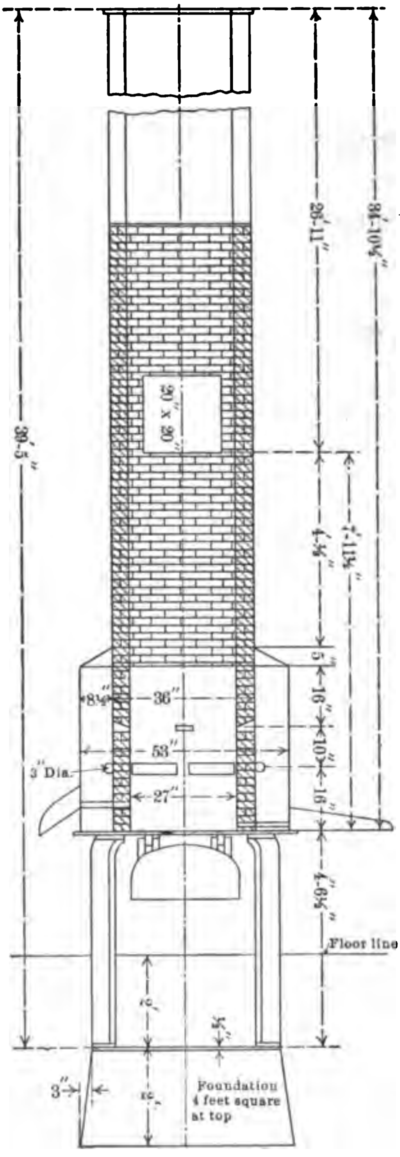
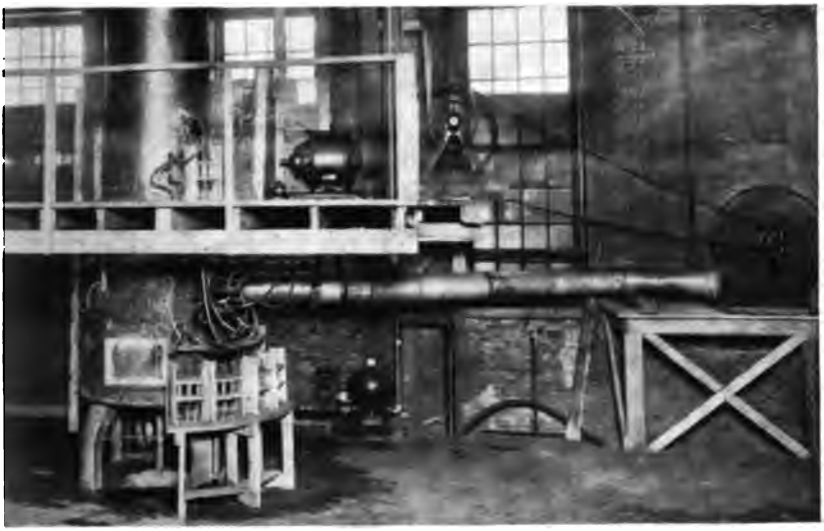


FIGURE 1.—Section of 36-inch foundry cupola.

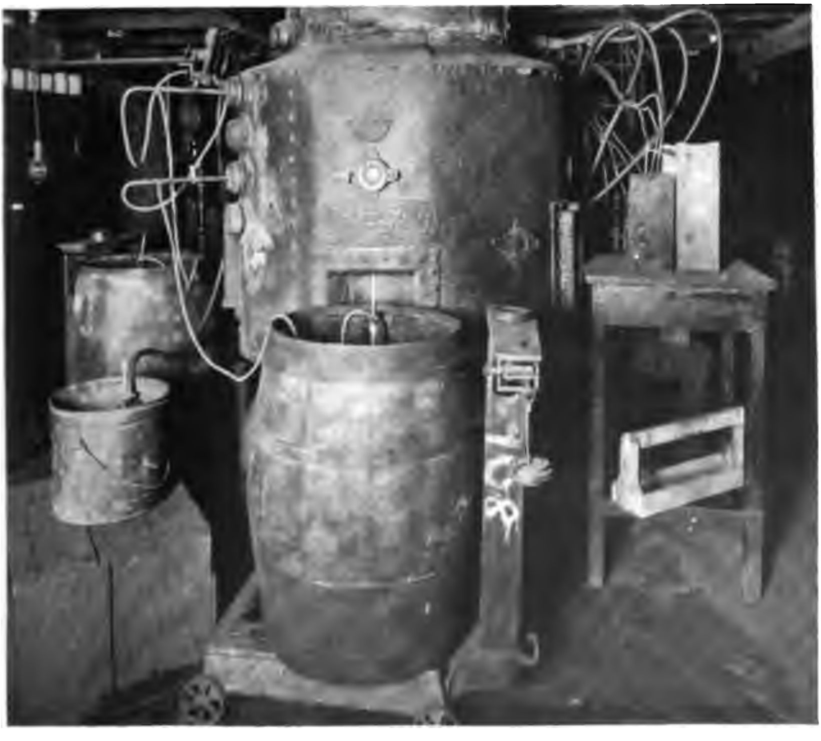
EQUIPMENT.

CONSTRUCTION OF CUPOLA.

A 36-inch standard Whiting cupola was installed. A No. 6 Sturtevant fan was connected to it by a 10-inch pipe 15 feet long. (See Pl. I, *A*.) The cupola is shown in section in figure 1, which gives the several dimensions. Attention is called to a few special features, as follows: Upper and lower tuyères were provided, but the upper ones were not used in any of the tests. The four lower horizontal tuyères measured 4 by 6 inches on the outside and 3 by 13 inches on the inside of the cupola and were 14 inches above the bottom. During tests the sand bottom was brought up to within 3 inches of the bottom of the tuyères in order to save as much coke as possible. The tuyère area was 96 square inches, and the area of the cupola, lined to 27 inches internal diameter, was 573 square inches, a ratio of 1 to 5.96.



A. CUPOLA WITH FAN AND CONNECTIONS.



B. APPARATUS FOR DETERMINING TEMPERATURES.

THEORETICAL SECTIONS AND PLANES.

For the purpose of the investigation the cupola was considered as divided into sections by four imaginary horizontal planes, situated as follows: One inch above the top of the inner opening of the tuyères, and 7, 13, and 19 inches above the top level of the tuyères. These imaginary planes, beginning at the bottom, are designated in this bulletin as *A*, *B*, *C*, and *D*.

Two-inch holes, as shown at *a*, *b*, *c*, and *d*, of Plate II, *A*, were cut through the wind box and inner shell along the lines at which the planes intersected the wall. Through each hole a 1½-inch pipe 10 inches long was passed, the inner end extending 1 inch past the inner shell into the brick lining, the outer end, extending 1 inch outside the wind box, being threaded to take a cap adapted to fit tightly the sample tube when inserted. The 1½-inch pipe was held in place and leakage of air from the wind box prevented by lock nuts inside and outside. The lock nuts were drawn up after proper packing was inserted between the nut and the inner wall of the wind box, thus making an air-tight joint. Around the pipe at the entrance of the inner wall no packing was used, as the brick lining was cut to make a tight fit, and the sample tubes after insertion were well plastered with fire clay at the point where they passed through the brick. The pressure was not sufficient to cause leakage through to the fuel bed, and all air admitted to the cupola passed through the tuyères. On the opposite side of the cupola at points designated as *a′*, *b′*, *c′*, and *d′* in Plate II, *A*, holes were cut at levels corresponding to those represented at *a*, *b*, *c*, and *d*, and were fitted with 3-inch pipes similarly to those just described. The exact location of the holes, considered with reference to the inside of the cupola, was as follows: *a* and *a′*, 1 inch above the top of the inner opening of the tuyères; *b* and *b′*, 6 inches above *a* and *a′*; *c* and *c′*, 6 inches above *b* and *b′*; and *d* and *d′*, 6 inches above *c* and *c′*. Later tests made necessary the insertion of a fifth tube at *e* and *e′*, 7½ inches above *d* and *d′*. All of these tubes except tubes *e* and *e′* passed through the wind box. The distance of 7½ inches instead of 6 inches between *d* and *e* was necessary in order to clear the wind box and avoid the difficulty of making the joint air tight. Subsequent tests showed that this placing of the tube had no material effect on the results.

FAN BLOWER UNSATISFACTORY.

It was decided to use a fan because a fan had been used in former tests, and because a blower causes pulsations in the blast. The fan was driven by two belts from a counter shaft (Plate I, *A*) connected by a single belt to a line shaft overhead. The fan was connected to the cupola by a 10-inch pipe 15 feet long. This pipe was not straight but had two bends of large radius to insure as little resistance as possible to the flow of air. In the preliminary tests a No. 6 Sturtevant fan blower was used and the pressure determined by means of a blast pressure gage, graduated in ounces and using water as the registering fluid. This gage was connected to the wind box, near the top, by means of a rubber tube, as shown in Plate II, *A*. Later, in order to get more delicate readings of pressure, a Pitot tube was installed in the straight part of the pipe, beyond the second bend near the cupola and connected with the gage. One of the main requirements of the investigation was to determine the quantity of air necessary and to insure the delivery of this quantity during each test.

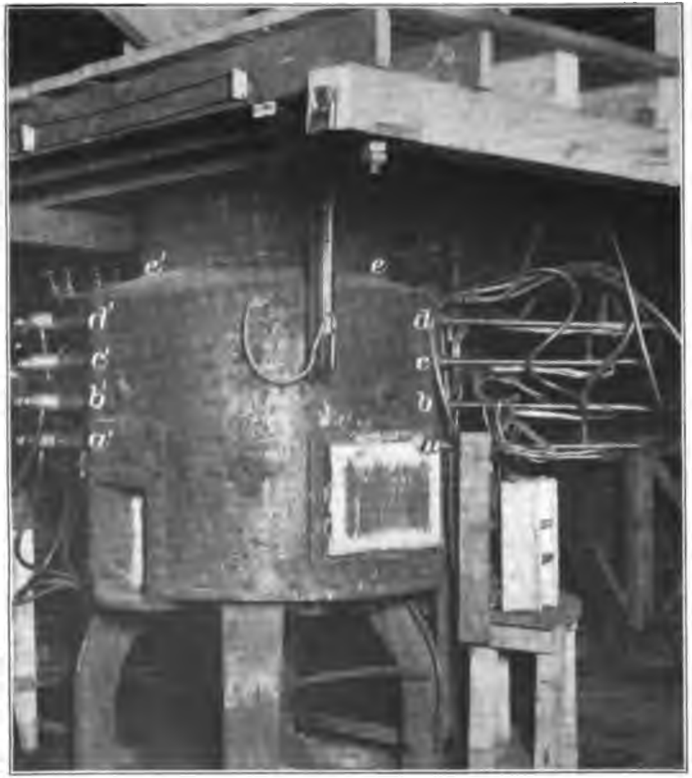
After many attempts to regulate and control the air, the task was found impossible and a No. 2 10-inch by 35-inch horizontal Roots blower was installed.

BLOWER DETAILS.

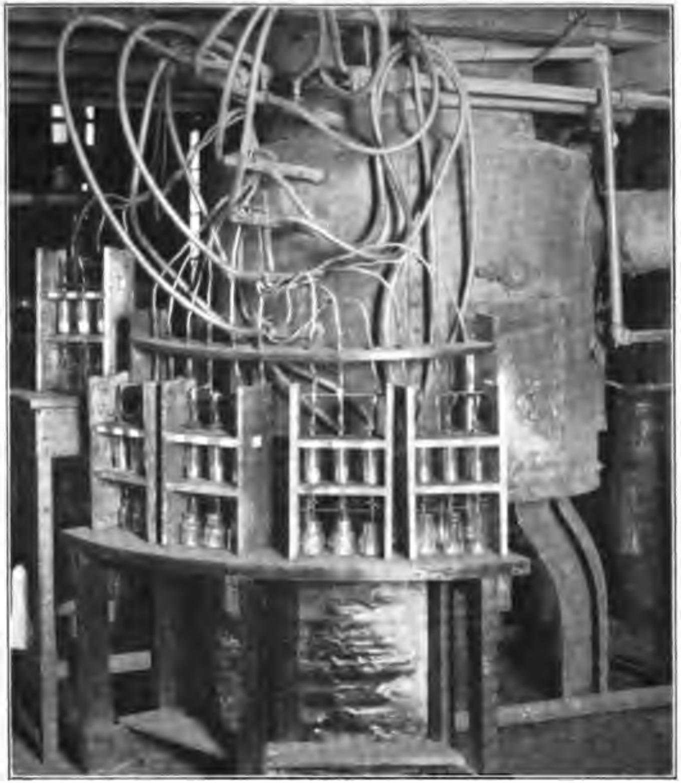
The blower and connections are shown in Plate III. A blower delivers a definite volume of air per revolution when running free, and the loss due to slippage is a definite and uniform quantity under any particular pressure. A reciprocating counter attached to the main shaft of the blower gave an accurate means of determining the revolutions, a Pitot tube connected to a recording pressure gage indicated the pressure at any time or the average over any period of time, and calculation gave the total volume of air delivered. In order to make the tests independent of possible delay and of overload difficulties, use of the line shaft was discontinued and a 10-horsepower motor was installed for operating the blower.

VOLUME OF AIR DELIVERED AND SLIPPAGE.

The blower was tested by the manufacturers at 2, 4, 6, 7, 8, and 16 ounces, and was recalibrated after installation. The curve shown in figure 2 was constructed to show the slippage in revolutions per minute at various pressures from 0 to 16 ounces. The amount of air delivered per revolution when running free was 4.8 cubic feet. The following example shows the method of arriving at the total volume of air delivered. During a 15-minute test the blower made 3,497 revolutions and each revolution delivered 4.8 cubic feet of air, so that the total number of cubic feet delivered was 3,497 times 4.8, or 16,785.6 cubic feet. The average pressure, as shown by a pressure gage connected with a Pitot tube inserted in the air pipe, was 5.3 ounces. The slippage of the blower at this pressure was 22 revolutions per minute. As each slippage revolution represented 4.8 cubic feet loss, the total loss during the test was 1,584 cubic feet ($22 \times 15 \times 4.8$). Deducting this loss of 1,584 cubic feet from the total air delivered with the blower running free ($16{,}785 - 1{,}584$) gives 15,201



A. VIEW OF CUPOLA SHOWING LOCATION OF TUBES.



B. APPARATUS FOR SAMPLING GASES.

cubic feet of air actually delivered in 15 minutes, or 1,013 cubic feet per minute.

MEASUREMENT OF PRESSURE.

The simple water manometer, used with the Pitot tube, required the undivided attention of an assistant, who made frequent readings over the whole period of the test in order that the average pressure might be determined. After the method of testing had been decided, a Bristol recording pressure gage, making a complete revolution in one hour, was connected with the Pitot tube. (See Pl. III.) A record was thus obtained which was continuous over the whole period of the test and facilitated the determination of a true average.

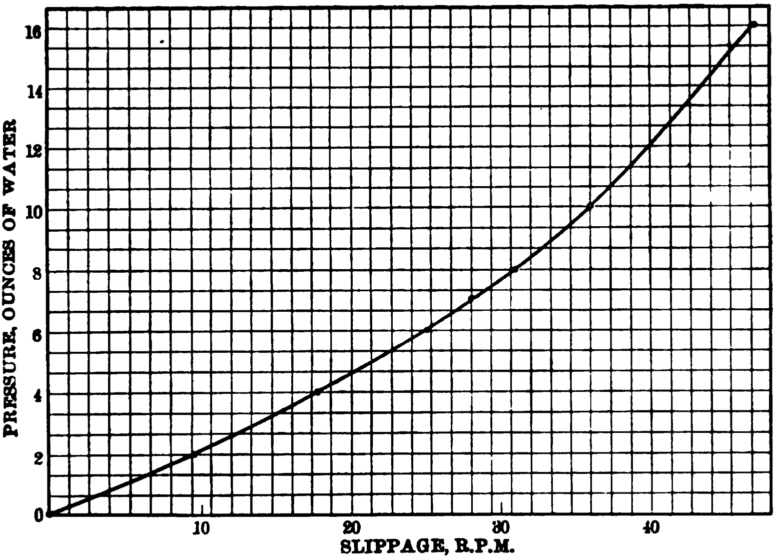


FIGURE 2.—Slippage of blower under various pressures.

PROCEDURE IN TESTS.

CHARGING OF CUPOLA.

In all tests, whether relating to the character of the gases or to the temperatures, the cupola was lined to 27 inches internal diameter. Coke alone, without iron or flux, was used. The investigation being designed to furnish data as to the action of the fuel, it was necessary to consider only that part of the cupola below and including the melting zone. Complications from the use of iron were thus avoided, and the experience of ordinary commercial practice does not indicate that the addition of this material would seriously affect the results obtained from coke alone. The sand bottom was brought up to within 3 inches of the bottom level of the tuyères. The tubes for collecting gas or measuring temperature were put in position. About 24 inches of coke was placed upon sufficient wood to insure proper kindling. The fire was lighted and the coke allowed to ignite and burn until the top showed bright. Coke in small quantities was added from time to time until well above the top tube, each succeeding charge being held until the preceding charge had burned through. After the last small charge had been added, sufficient time was given to insure its burning evenly over the whole surface of the bed, thus indicating that the burning was over and through the whole bed of coke and was not localized as sometimes happens when proper precautions are not taken. The kindling wood was always completely burned before the last coke was added. This last addition of coke brought the top of the charge to within 6 inches of the charging door. The total weight of coke charged was approximately 750 pounds for each test. Ten minutes after the last coke had been added the blast was turned on and was continued for 15 minutes before the test began. The reason for allowing this length of time was to insure uniform conditions over the whole fuel bed, and was more than that necessary in regular commercial practice to cause the appearance of iron at the cupola spout, an indication that melting has begun.

AIR SUPPLY.

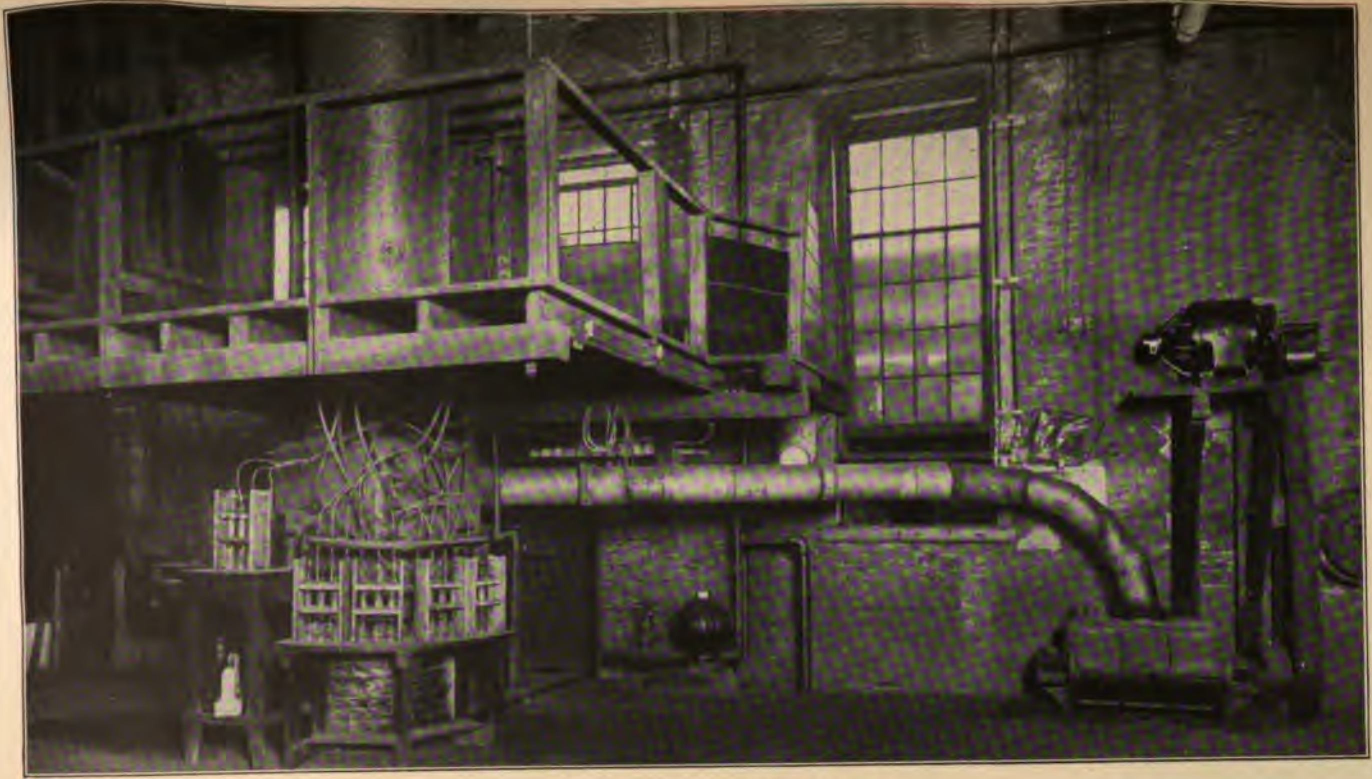
Preliminary tests were made with varying volumes of air per minute, the results suggesting the use of 1,000 cubic feet per minute as a normal condition. As the 36-inch cupola, lined to 27 inches, can melt about 2 tons of iron per hour, 1,000 cubic feet of air per minute checks well with the usual assumption that 30,000 cubic feet of air is required to melt a ton of iron. The varying pressures due to different sizes of coke, the position of pieces of coke with reference to other pieces and the side walls, the effect of slagging and hanging and of other conditions, made impossible the exact regulation of the air supply, but the average of all tests approximated 1,000 cubic feet per minute.

GAS SAMPLING.

In investigating the cupola gases it was necessary to decide on the best method of obtaining samples that would represent the gases in the different cross sections of the fuel bed, and the number of such samples necessary at each cross section, as well as the number of sections.

POINTS OF SAMPLING.

It was decided to consider the fuel bed as being divided by four imaginary planes, located as follows: 1 inch above the top of the inner opening of the tuyères, and 7, 13, and 19 inches above. In subsequent discussion these planes are designated, starting with that



CUPOLA WITH BLOWER AND CONNECTIONS.

1 inch above the top level of the tuyères, as *A*, *B*, *C*, and *D*, and the points from which samples were taken, beginning with the center, as 1, 2, and 3, 2 being 4½ inches from the center, and 3 being 9 inches from the center and 4½ inches from the lining. Figure 3 shows a vertical section of the cupola and the positions of the imaginary planes and of the sample tubes in place. As figure 3 shows, all samples were taken from vertical radial planes that intersected the tuyères, it being assumed that the gases were the same over any other similar area in the cupola because the entrance of the blast was through tuyères, the inner openings of which extended practically the whole way around the interior circumference of the lining. Simultaneous samples taken at other points showed reasonable although not exact agreement.

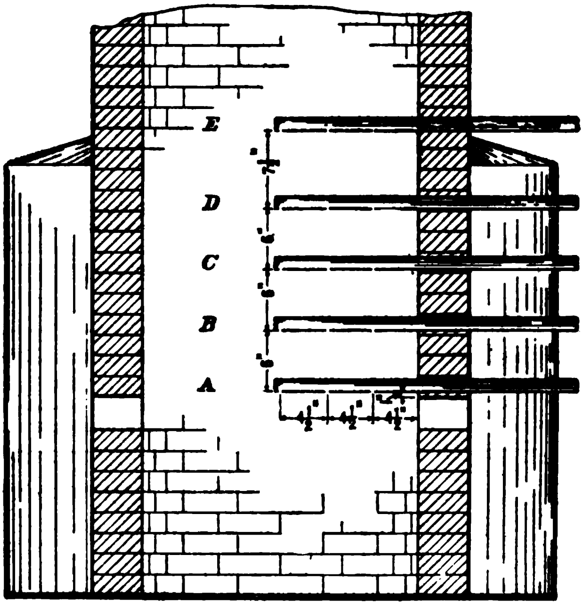


FIGURE 3.—Position of planes and gas-sampling tubes.

The preliminary work showed the necessity of examining the bed above plane *D* (fig. 3), so that examination was made of the gases in a fifth imaginary plane designated as plane *E*. This plane was 7½ inches above plane *D* and 26½ inches above the top level of the tuyères.

GAS-SAMPLING APPARATUS.

The type of gas-sampling tube used in this work is shown in cross section in figure 4. *A* in the figure represents a 1¼-inch iron pipe 48 inches long, one end closed by a circular piece of steel welded in. Three ¼-inch, 3/16-inch internal diameter, copper tubes, for the collection of the gas samples (represented by *a*, *b*, and *c*, fig. 4) were brazed into small holes cut through the wall of the pipe and made flush with the outside. These gas-collecting tubes, as well as the inclosing pipe, were kept cool by cold water which entered the outer end through a ½-inch copper tube (*d*, fig. 4) and passed out through a ¼-inch iron pipe (*e*, fig. 4). The exit ends of the small tubes, as well as the ½-inch inlet, were held in place and the whole made water tight by brazing.

The gas-collecting tubes were connected by ¼-inch lead tubes to ¼-inch copper tubes leading into the wash bottles. The copper tubes were provided with a T at a point convenient for attachment to the mercury-filled sample receivers. The connection was made by means of a 1-mm. internal diameter glass tube, through which a portion of the gas was drawn off continuously from the larger stream. The wash bottle was introduced beyond the point where the gas sample was taken and served to indicate whether the gas was flowing properly through the tubes. No aspiration was necessary, as the sampling tubes extended into the fuel bed and the positive pressure of the blast forced the gases through the tubes. The portion taken for a sample was drawn from the main flow by the flow of the mercury out of the gas receivers. Details of the apparatus are shown in Plate II, *B*. More complete discussion of the method of sampling and analysis used can be found in Bulletin 12 of the bureau.[a]

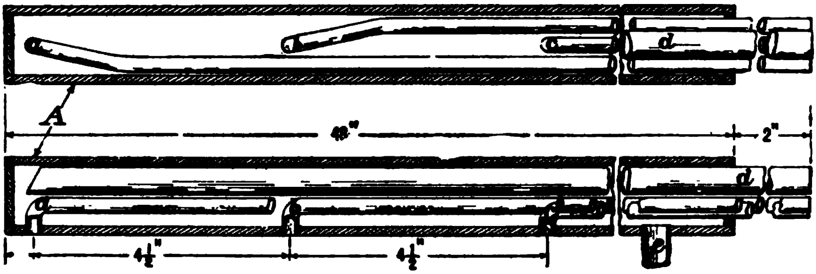


FIGURE 4.—Section of gas-sampling tube.

METHOD OF USE.

The water-cooled tubes were inserted and the cooling water turned on before the cupola was charged. All of the tubes were inserted a distance that brought hole 1, or the hole nearest the inner end of the tube (fig. 3), at the exact center of the cupola; hole 2, 4½ inches from hole 1 toward the lining; and hole 3, 4½ inches from hole 2 and 4½ inches from the lining.[b] This placing of the tubes divided the 13½ inches from lining to center into three equal parts. When the blast was turned on, the bubbling of the water in the wash bottles attached to the ends of the tubes gave evidence of the flow of gas. If the gas did not flow properly, the small tubes were disconnected at the point where they joined the lead tube and a wire was run through to remove the obstruction; or, as later practiced, compressed air was blown through from the end of the lead pipes. The latter procedure had the advantage of clearing the whole system and saved much time.

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[a] Frazer, J. C. W., and Hoffman, E. J., Apparatus and methods for the sampling and analysis of furnace gases. 1911. 22 pp.

[b] The points in the fuel bed at the holes here mentioned are subsequently referred to in text and in tables as "locations."

After all the parts had been tested and gas was flowing freely, the mercury-filled sample receivers were attached. Fifteen minutes after the blast had been started the cocks on all the receivers were turned simultaneously and samples were taken for a period of 15 minutes. One set of three samples was taken from each imaginary horizontal plane, a total of 15 samples for each test. On several of the tests a sixth set was taken at a point above the charge, to show the average composition of the gases at that position. (See Pl. I, *A*.)

RESULTS OF ANALYSES.

The results of analyses of the gases from separate tests, as well as the average for the series, are given in table 1, as follows:

TABLE 1.—*Analyses of cupola cases.*

[L. L. Satler, jr., analyst.]

Plane.[a]	Location No.[b]	Test No.—															Average.		
		1.			2.			3.			4.			5.					
		CO_2	O_2.	CO.	CO_2.	O_2.	CO.	CO_2.	O_2.	CO.	CO_2.	O_2.	CO.	CO_2.	O_2.	CO.	CO_2.	O_2.	CO.
A	1	5.9	0.0	25.1	8.8	0.0	19.5	17.1	0.7	4.9	16.8	0.3	6.0	11.6	0.0	15.5	12.0	0.2	14.2
	2	10.3	9.5	1.6	10.3	0.1	16.9	11.0	0.4	15.5	6.0	0.5	24.2	13.8	0.1	11.6	10.3	2.1	14.0
	3	1.1	19.6	0.0	2.5	18.1	0.0	3.1	17.6	0.0	9.5	10.6	1.1	7.3	13.1	0.3	4.5	15.8	0.2
B	1	7.9	0.0	21.3	15.6	0.5	8.3	12.2	0.0	14.0	14.0	0.0	11.1	15.6	0.3	7.5	13.1	0.1	12.4
	2	18.3	1.3	1.7	11.8	0.1	14.7	13.1	0.3	12.0	9.2	0.0	18.8	10.3	0.0	17.2	12.5	0.3	12.9
	3	10.4	10.1	0.1	14.0	6.2	0.7	8.1	12.4	0.0	12.4	7.8	1.1	12.7	7.8	0.4	11.5	8.9	0.5
C	1	7.0	0.0	23.2	13.9	0.2	10.9	12.9	0.0	13.1	11.7	0.0	14.7	14.1	0.5	10.1	11.9	0.1	14.4
	2	15.0	0.2	8.6	14.2	0.0	13.1	13.8	0.2	11.2	8.2	[c]0.7	19.7	.....	.....	.....	12.8	0.1	13.2
	3	15.2	4.9	0.4	15.0	4.7	1.5	13.2	7.3	0.5	16.6	2.8	1.2	15.1	4.8	1.4	15.0	4.9	1.0
D	1	6.3	0.0	24.0	11.3	0.0	15.3	10.8	0.0	16.3	9.1	0.0	18.9	11.4	0.0	15.8	9.8	0.0	18.1
	2	12.1	0.0	14.8	11.0	0.1	15.8	13.3	0.1	12.3	9.1	0.0	19.8	12.1	0.0	14.2	11.5	0.0	15.4
	3	17.6	0.7	4.1	17.0	0.7	4.9	16.9	[c]2.6	1.8	16.5	0.1	6.9	16.6	0.2	6.4	16.9	0.4	4.8
E	1	6.7	0.0	24.1	9.5	0.0	18.3	10.1	0.0	17.3	7.1	0.3	21.5	9.7	0.0	18.1	8.6	0.0	19.9
	2	10.6	0.0	16.6	10.4	0.0	16.7	.....	.....	.....	8.5	0.0	19.0	10.9	0.0	16.0	10.1	0.0	17.1
	3	16.5	0.3	6.8	15.8	0.0	7.8	16.8	0.0	5.4	12.1	0.2	14.1	14.9	0.0	8.8	15.2	0.1	6.8

[a] Refers to imaginary horizontal plane, see pp. 10–11.
[b] Refers to holes in sampling tube, see p. 12.
[c] Probably due to channel flow of air; not included in average.

As was to be expected, samples of gas taken at different times showed many variations. The flow of the blast after entering the tuyères was probably changing during the whole period, seeking escape inward as well as upward along the lines of least resistance. The largest volume undoubtedly flowed up the side walls, and this, as well as the part penetrating toward the center, was more or less deflected by the obstructions encountered. Effects of such changes were especially noticeable during preliminary work, when coke was charged in varying sizes as received. This explains why more uniform results are obtained in practice by the use of by-product coke or anthracite coal. During some of the first tests, in which large pieces of coke were used exclusively, oxygen persisted through the whole charge and was found in the gas sample taken above the charge. This condition was no doubt due to the fact that the large pieces of coke against the wall allowed a free and practically unobstructed passage to a part of the gases. In the tests the results of which are given in tables 1 to 5 all coke was broken into 3-inch cubes or less. The analyses of samples of the gases present above the charge under the conditions of the tests showed no oxygen, typical analyses being as follows:

Analyses of gases present above cupola charge.

[L. L. Satler, Jr., analyst.]

Kind of gas.	Percentage of gas in location—[a]		
	1.	2.	3.
	Per cent.	*Per cent.*	*Per cent.*
CO_2	8.5	10.2	14.5
O_2	0.0	0.0	0.0
CO	20.6	17.8	8.4

[a] Explanation of locations given in footnote on p. 12.

DISCUSSION OF RESULTS.

Figures 5, 6, and 7 have been constructed from table 1. The planes of the cupola from which the gases analyzed were taken are represented as ordinates and the percentages of carbon dioxide, oxygen, and carbon monoxide as abscissas. Carbon dioxide (CO_2) is the product of complete combustion. Carbon monoxide (CO) is the product of incomplete combustion. The oxygen (O_2) of the blast entering at the tuyères comes in contact with hot coke and the burning or combustion takes place, forming CO_2. This reaction produces heat and raises the temperature. If the CO_2 comes in contact with incandescent coke it takes up carbon from the coke and changes to CO. This reaction takes up heat and reduces the temperature.

GASES AT CENTER LINE OF CUPOLA.

Figure 5, representing the conditions at the center line of the cupola, shows the practical absence of oxygen at all sections, the small quantity recorded being within the range of the probable error of the method of analysis or attributable to the chance penetration of some small amount of the blast. The changes taking place in the first 6 inches show an increase of CO_2 and a decrease of CO, and from this point upward a rapid falling off of CO_2 and a corresponding increase of CO.

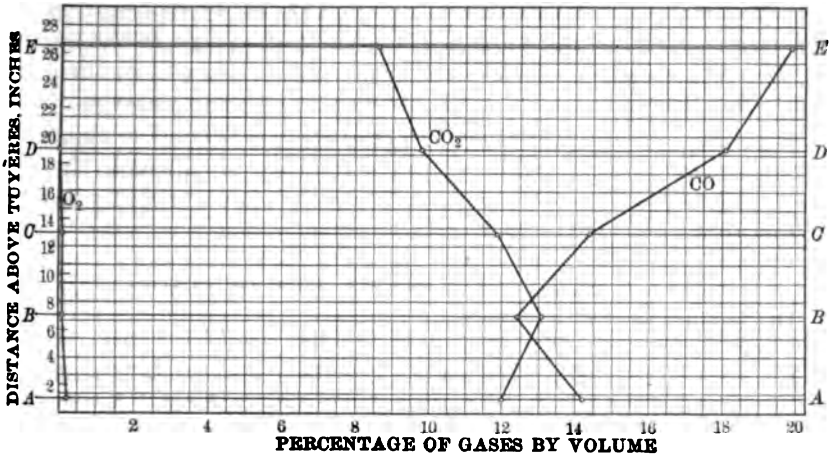

FIGURE 5.—Diagram showing variation in percentages of O_2, CO, and CO_2 at different heights (planes) on the center line of the cupola. Lines *A*, *B*, *C*, *D*, and *E* represent the imaginary planes.

GASES 4½ INCHES FROM CENTER LINE OF CUPOLA.

Figure 6 represents the conditions 4½ inches from the center and by the percentage of oxygen shown indicates the penetration of the blast at plane *A*. As shown in the figure, the percentage of oxygen rapidly decreased, being practically nothing 6 inches above, at plane *B*. Comparing the conditions at the center and 4½ inches from the center as represented in the figures, the CO_2 percentages in both cases show the same general increase through the first 6 inches. At 4½ inches from the center there is no material change during the movement through the second 6 inches. From this point upward

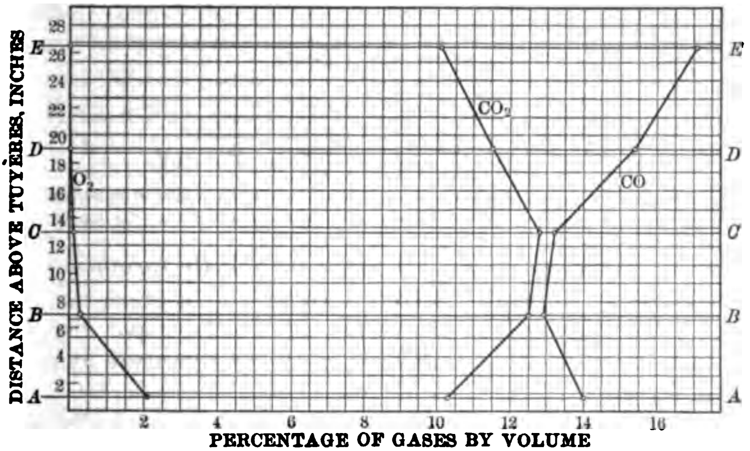

FIGURE 6.—Diagram showing variation in percentages of O_2, CO, and CO_2 at points 4½ inches from the center of the cupola. Lines *A*, *B*, *C*, *D*, and *E* represent the imaginary planes.

through the fuel bed the percentage of CO_2 at 4½ inches from the center decreases but not so rapidly as the percentage at the center. The CO percentage 4½ inches from the center decreases in the same general manner as the CO at the center during the passage of the gases through the first 6 inches. Through the second 6 inches no material change takes place. From this point up through the bed the proportion of CO at 4½ inches increases but not so rapidly as that at the center.

GASES 9 INCHES FROM CENTER LINE OF CUPOLA.

Figure 7 represents the conditions 9 inches from the center and 4½ inches from the lining. One inch above the tuyères the oxygen of the blast is reduced by an amount necessary to form 4.5 per cent CO_2, and the formation of CO_2 rapidly increases in the first 6 inches, with corresponding decrease in O_2 and with little formation of CO. These conditions indicate a fierce burning and a great rise in temperature. This assumption is borne out by the rapid rise of the temperature at plane *B* as compared to the temperature at plane *A*. (See also fig. 15.)

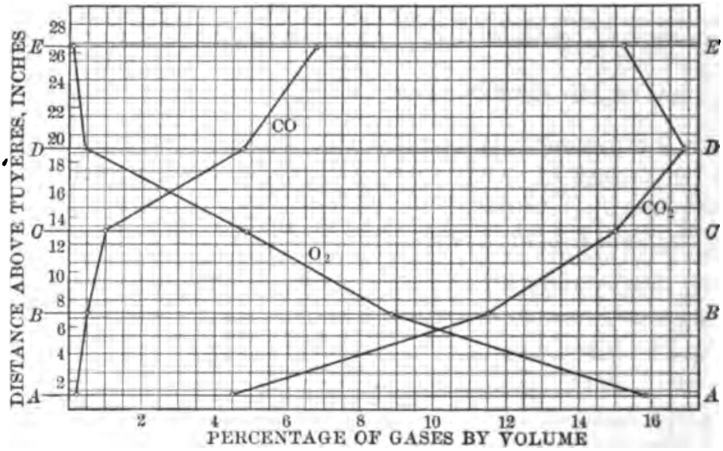

Figure 7.—Diagram showing variation in percentages of O_2, CO, and CO_2 at points 9 inches from the center and 4½ inches from the lining of the cupola. Lines *A*, *B*, *C*, *D*, and *E* represent the imaginary planes.

From plane *B* the oxygen rapidly decreases to practically nothing just above plane *D*. The CO_2 remains practically constant from plane *B* to plane *C*, the CO increasing slightly. During the passage of the gases through the next 6 inches both CO_2 and CO increase. This zone of highest CO_2 content, as yet not materially affected by the rise of CO, is the hottest part of the entire fuel body. This condition is also indicated in figure 15. From this point to the next plane (*E*) 7½ inches above, the CO_2 decreases and the CO increases. The temperature decreases.

The temperature conditions at plane *E* and at plane *C* are nearly the same, but the conditions for melting are materially different. At plane *C* there is a supply of oxygen that would undoubtedly cause oxidation of the metal and resultant loss. Whether the amount of iron melted at this plane would be oxidized sufficiently to affect seriously castings made from the whole tonnage was not determined by these investigations, but if certain conclusions, based on the tests at St. Louis,[a] as to the effect of burned metal on casting are correct, it is safe to assume that the chances favor the production of defective castings.

PROBABLE COMBUSTION AREA.

The broken line in figure 8, represents the upper boundary of the region of gases containing free oxygen.

As indicated in figure 8, the actual combustion of the fuel takes place in the fuel bed around a region having the shape of an inverted cone; the apex of this cone is at the center on the level of the bottom of the tuyères and its surface flares out to the lining at a point 20 inches above. If melting be kept above the base of this cone, no oxidation will occur.

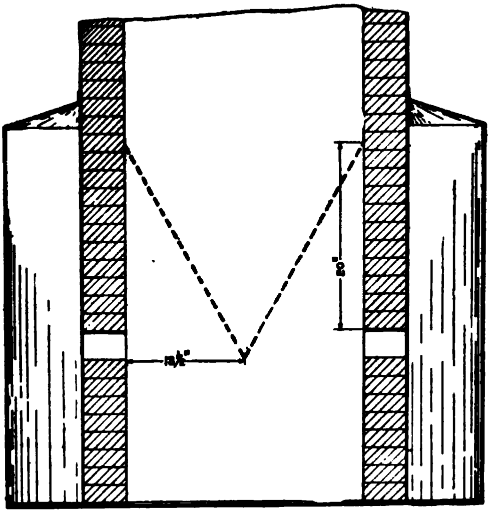

FIGURE 8.—Section of cupola showing upper boundary of region of combustion.

PROBABLE LINE OF HIGHEST TEMPERATURE.

Considering the region of gases highest in CO_2 content and devoid of O_2 (see figs. 5, 6, 7, and 8), and considering the plotted line of highest CO_2 content at each plane as a line of demarcation, the line *ab* in figure 9 shows in cross section the probable shape of the top of the fuel bed as defined by the points of highest temperature.

If it were possible so to charge the cupola that melting would take place along or just above such a line (or, rather, surface) as is indicated in this figure, ideal results would be obtained both as regards temperature and absence of oxidation. Since it is not possible to confine the melting to this irregular region, the best condition for melting is obtained at that section across the whole of the fuel bed that shows the highest temperature together with absence of oxygen. This condition, as shown by the tables of temperatures and of analyses of the gases, exists just above plane *D*, about 20 inches above the tuyères. It is not possible to do all melting at this particular plane, but the melting can be so confined and regulated that none takes place below this plane.

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[a] Moldenke, Richard, The coke industry of the United States as related to the foundry: Bull. 3, Bureau of Mines, 1910, p. 19.

The height of the melting zone above this plane is determined by the physical condition of the coke and the rate of heat absorption of the iron. If the coke is porous, the charges of iron should be small to prevent the coke burning out and letting the iron down into the oxidizing zone before melting is accomplished. If the coke is heavy and dense, or if anthracite coal is used, the charges may be made larger, as the fuel will burn more slowly and give a longer time for melting. In some region above this zone of highest temperature the temperature is still high enough to melt iron but is not high enough to impart heat quickly and to give hot iron. This melted iron passes through the lower zones, although the temperature in these zones be exceedingly high, too rapidly for the absorption of enough heat to raise its temperature materially, and cold iron is the result. The experiments here reported confirm the general opinion that the hot test part of the cupola is where the lining is most burned out. A curved line drawn to represent the burned-out lining corresponds closely with the curves drawn to represent the heat absorbed at the several planes previously described.

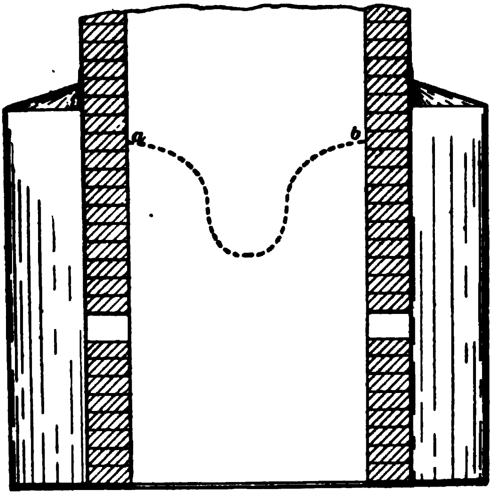

FIGURE 9.—Probable line of highest temperature.

ALTERATION OF CUPOLA LINING.

A study of the data shown in table 1 led to the conclusion that the amount of coke necessary for melting could be reduced by changing the lines of the cupola from the straight to the boshed form. Accordingly the lining was drawn in to 23 inches at the tuyères, tapered to the original lines of 27 inches at 15 inches above the tuyères, and continued straight from this point. It was thought that the blast entering at the tuyères would penetrate farther toward the center of the cupola and a smaller volume of air would escape up the side walls without first coming in contact with hot coke. This, it was hoped, would cause the loss of all the oxygen at a lower point in the fuel bed and would lower the zone at which the iron could be melted without its quality being seriously affected. The zone of highest temperature was expected to follow the zone where oxygen disappeared, as in the case of the straight lining, but no attempt was made to determine whether this relation held.

RESULTS OF ANALYSES OF GASES FROM CUPOLA OF BOSHED CONSTRUCTION.

Table 2 shows typical analyses of gases sampled after alteration of the lining but taken from the same locations as were the gases whose analyses appear in table 1. Table 2 follows:

TABLE 2.—*Analyses of gases from cupola of boshed construction.*

[L. L. Satler, jr., analyst.]

Plane.[a]	Location No.[b]	CO_2.	O_2.	CO.
		Per cent.	*Per cent.*	*Per cent.*
A	1	11.1	1.0	14.3
	2	0.3	20.4	0.0
	3	0.2	20.7	0.0
B	1	14.8	1.2	8.4
	2	11.1	9.3	0.0
	3	2.2	18.4	0.0
C	1	14.6	0.0	10.6
	2	16.0	4.0	0.7
	3	5.4	15.2	0.3
D	1	10.3	0.0	17.3
	2	15.7	0.0	8.0
	3	16.9	3.3	0.7
E	1	7.5	0.0	21.9
	2	13.2	0.0	12.5
	3	17.1	0.5	4.7

[a] See p. 7.

[b] See p. 12.

The penetration of oxygen was affected, as may be seen by comparing the analyses with those of table 1, but the oxygen persisted up through the whole bed. The analysis of the gas at the point represented by D3 of the table shows 3.3 per cent O_2, as compared with 0.4 per cent at the corresponding location with the original straight lining (table 1). The drawing in of the lining materially increased the blast pressure (from 3.6 to 5.5 ozs.), and the flow of gas was accelerated to such an extent that the time of contact with the coke was not sufficient to rob the blast of its oxygen.

TEMPERATURES.

DIFFICULTIES OF MEASUREMENT.

Measuring temperatures in the fuel bed of the cupola presents many difficulties and all attempts to get actual temperatures failed. Descriptions of the several forms of apparatus used in the various tests here reported are given somewhat in detail for two purposes: (1) To draw attention to the many difficulties encountered during this part of the investigation, and (2) to render these experiments more serviceable to future investigators. Diligent search of all available literature failed to reveal accounts of attempts to determine the actual temperature in the interior of the fuel bed of the cupola or in other metallurgical operations on the same scale. Measurements have been attempted at points on or near the furnace walls, but not at points over a considerable cross-sectional area.

USE OF PLATINUM-RHODIUM THERMOCOUPLES.

It was first decided to take temperatures by means of platinum-rhodium thermocouples introduced into the fuel bed through clay tubes, as shown in figure 10. The thermocouples were so placed that readings were obtained at the center of the cupola (*a*, fig. 10), at a point 4½ inches from the center toward the lining (*b*, fig. 10), and at a point 9 inches from the center and 4½ inches from the lining (*c*, fig. 10). The positions of the points are the same as those from which gas samples were taken. The tubes were specially prepared from mixtures of the most highly refractory clays that could be obtained. In plane *A*, just above the tuyères, the tubes stood up well, and direct readings of temperature were obtained. Readings over 15-minute periods, taken each minute, showed an average temperature of 2,593° F., 2,430° F., and 1,576° F., at points represented by *a*, *b*, and *c* of figure 10; the maximum variation at any one point was 122° F. Above plane *A* the tubes were sheared off at their point of entrance through the wall by the movement of the charge. To prevent this shearing a pier of magnesite brick was constructed to

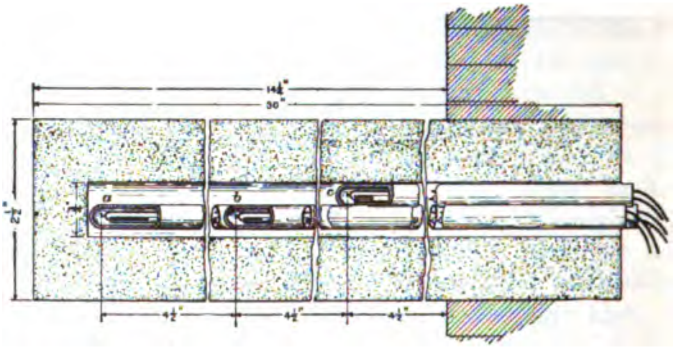

FIGURE 10.—Section of fire-clay tube with platinum-rhodium thermocouples inserted.

support the ends of the tubes. Although the pier prevented shearing, it was of no avail in obtaining readings, as the clay tubes were melted at all planes above plane *B*. At the center of the cupola in plane *B* the thermocouple was melted, indicating a temperature above 3,100° F. As a result of these tests, the use of the platinum-rhodium thermocouples was abandoned.

USE OF OPTICAL PYROMETER AND WATER-COOLED TUBE.

The next step was an attempt to obtain temperatures with an optical pyrometer by observation through a water-cooled iron tube with a glass-covered opening at one end. A cross section of the tube is shown in figure 11. It was fully appreciated that the readings obtained would not represent actual temperatures on account of the cooling effect of the water-cooled tubes, but it was hoped that approximate temperatures showing the temperature differences between planes would be obtained and that they could be expressed in degrees of temperature with an explanation as to the limitations of the method. It was thought that at any given point the highest reading obtained during the whole period of the test would approximate the true temperature at that point. However, the averages of five temperature readings made at each of five points at different heights on a vertical line at the center of the cupola proved to be practically the same as were the highest temperature readings at each of the points. It was thought that the true temperatures at the center of the cupola might possibly be as uniform as these readings indicated, since no analysis of the gases taken at any time showed an appreciable amount of oxygen, and therefore indicated that there was no combustion. Further tests with the ends of the tubes at varying distances from the side wall continued to show for all points in any vertical line practically the same average temperature and the same high temperature. It was thought that this condition might be due to the fact that the ends of the water-cooled tubes were in direct contact with the coke.

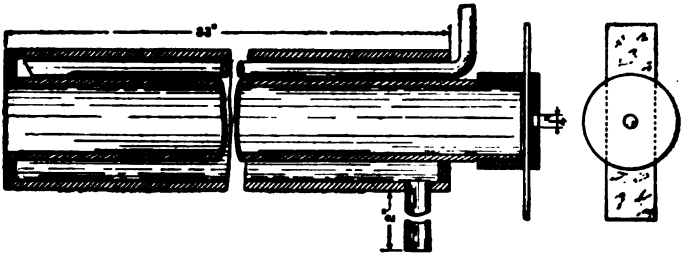

FIGURE 11.—Section of water-cooled iron tube used in taking temperature readings.

USE OF CLAY PROTECTING TIPS.

With the hope of further perfecting the apparatus, a clay protecting tip (fig. 12) was placed over the end of each of the water-cooled tubes, extending a distance of 2 inches. This made possible the reading of the temperature of coke that was not in direct contact with the water-cooled tubes. These protecting tips were melted, like the clay tubes, but held up long enough to show the same uniform readings as with the unprotected tubes.

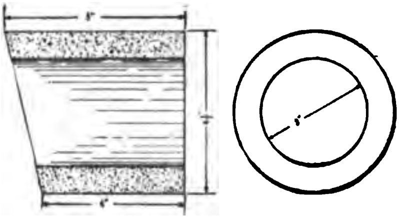

FIGURE 12.—Section of clay protecting tip.

DISCUSSION OF RESULTS.

Tables 3 and 4 show typical readings of temperatures taken through water-cooled tubes with an optical pyrometer. The tables follow:

TABLE 3.—*Temperatures*, °*F*.[a]

Plane.			
A	*B*	*C*	*D*
2,736	2,827	(b)	2,827
[c]2,862	(b)	(b)	(b)
2,653	2,966	2,934	2,786
2,712	(b)	3,015	2,741
2,736	3,036	2,988	2,692
(b)	[c]3,083	(b)	(b)
2,742	2,939	[c]3,052	[c]2,961
2,800	2,811	3,009	(b)
[d]2,750	[d]2,942	[d]3,000	[d]2,802

[a] All temperatures taken at center of cupola with Wanner optical pyrometer at intervals of 2 minutes.
[b] Cold; not included in total. [c] Maximum. [d] Average.

TABLE 4.—*Temperatures*, °*F*.[a]

Plane.				
A	*B*	*C*	*D*	*E*
2,584	[b]3,027	2,993	2,579	2,856
2,763	2,939	[b]3,020	2,674	2,786
2,988	2,809	2,925	2,871	2,696
3,020	2,804	2,851	2,570	2,763
2,826	2,971	2,809	2,856	[b]2,914
[b]3,067	2,752	2,687	[b]2,908	2,883
3,060	2,817	2,809	2,826	2,800
2,939	2,773	2,593	2,692	2,800
3,033	2,678	(c)	2,766	2,817
2,671	2,790	(c)	2,874	2,680
2,790	2,955	2,851	2,889	2,797
2,899	2,851	2,674	2,719	2,755
2,934	2,817	(c)	2,730	2,851
[d]2,890	[d]2,845	[d]2,822	[d]2,766	[d]2,800

[a] All temperatures taken at center of cupola with Wanner optical pyrometer at intervals of 1 minute; 2-inch clay protecting tips on ends of water-cooled tubes.
[b] Maximum. [c] Cold; not included in total. [d] Average.

USE OF WATER-COOLED COPPER TUBE.

The tube shown in figure 13 was finally adopted as a device for determining the amount of heat absorbed per minute at different depths in the fuel bed. A ¾-inch copper tube 32 inches long was closed at one end by welding in a circular piece of steel. A ¼-inch tube inserted at one end and extending to the farther end provided a means for circulating water through the tube. This tube was inserted different distances into the fuel bed and the heat absorbed by a measured quantity of water during a definite period of time was determined. The flow of water was kept as nearly constant as possible. The average amount for each test was 150 pounds in all, or 10 pounds per minute. The temperature of the inlet and outlet water was obtained by means of mercurial thermometers. Readings of the temperature of the inflowing and outflowing water were made each minute during a test. These readings were separately averaged. The difference between the average temperatures over a definite period multiplied by the total weight of water circulating through the tube during that period gives the total heat absorbed. This total divided by the total number of minutes of the test gives the heat absorbed per minute. Figure 14 shows how the tubes were placed in the cupola. The copper tubes were thoroughly cleaned before each test and the conditions were made as uniform as possible in all respects. Only two tubes were used during any one test. They were placed at least 12 inches apart in order to prevent a possible reduction of temperature by radiation of heat from coke surrounding one tube to the other tube if the two

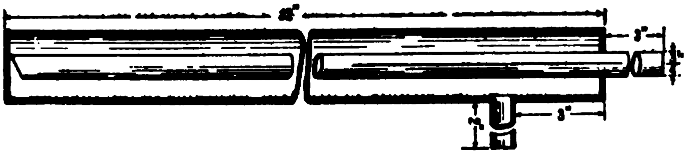

FIGURE 13.—Section of water-cooled copper tube used for determining amount of heat absorbed per minute at different depths of the fuel bed.

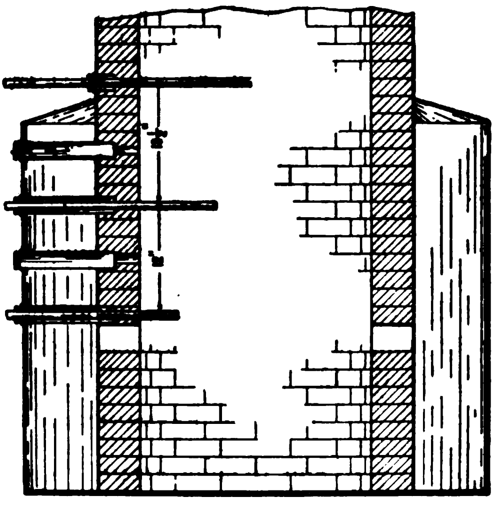

FIGURE 14.—Section of cupola showing location of water-cooled copper tubes.

were in close proximity. Plate I, *B*, shows details of apparatus as used for determining the heat absorbed.

RESULTS WITH USE OF WATER-COOLED COPPER TUBES.

Table 5 shows the heat absorbed per minute at the different planes. The tubes were inserted in the fuel bed to distances corresponding with the points from which the gas samples were taken. For location 1 of the table the tube was inserted 13½ inches (from the lining to the center of cupola); for location 2, 9 inches; and for location 3, 4½ inches. Table 5 follows:

TABLE 5.—*Heat absorbed per minute at different locations in the fuel bed, B. t. u.*

Plane.	Location.	Length of tube exposed.	Test No.—						Average.
			1.	2.	3.	4.	5.	6.	
		Inches.							
A	1	13½	347.8	304.0	351.2	311.8	292.4	399.4	334.4
	2	9	191.1	161.7	163.3	222.3	199.3	189.5	187.9
	3	4½	20.4	19.5	38.2	21.4	27.7	22.6	25.0
B	1	13½	495.1	506.0	594.1	514.5	559.0	534.5	533.9
	2	9	339.4	344.9	363.1	315.7	343.2	385.1	348.6
	3	4½	158.8	131.4	144.0	118.9	155.1	128.6	139.5
C	1	13½	612.0	615.0	....	541.3	545.9	625.2	587.9
	2	9	362.2	399.0	450.2	457.5	456.8	460.3	431.0
	3	4½	110.3	178.5	186.1	189.8	220.1	238.7	187.3
D	1	13½	598.5	....	606.4	623.3	582.7	651.4	612.4
	2	9	453.3	466.3	449.4	472.0	432.6	449.0	453.8
	3	4½	238.9	242.3	229.6	236.8	243.9	....	238.3
E	1	13½	613.8	587.7	558.6	572.5	609.0	614.5	592.7
	2	9	400.8	425.3	407.0	401.0	401.6	386.1	403.7
	3	4½	244.0	242.1	255.0	202.7	248.1	....	238.5

The heat measurements by the copper tubes show the heat absorbed by the tubes over the whole distance to which they were inserted and not the heat at some particular point in the fuel bed. As in the case of the gas analyses, the observations varied considerably. Allowance being made for the crudeness of the method, the variations are not surprising.

GRAPHIC REPRESENTATION OF RESULTS.

Figures 15 and 16 show graphic representations of the results.

AVERAGES.

Figure 15 gives a graphic representation of the averages of the observations at each location, which are believed to show the relative temperatures of the several planes measured. The heat absorbed per minute is shown as abscissas and the heights (planes) as ordinates. From this figure it will be noted that the greatest amount of heat was absorbed at plane *D*. At plane *A*, with tube inserted 4½ inches, the cooling effect of the blast is evident, the heat absorbed being small.

As the height above the tuyères increases the temperature steadily increases up to plane *D*. Curve 1, representing the heat absorbed in each section when the tubes were inserted over the whole radius of the cupola, shows that the height above the tuyères where the greatest heat existed over the whole cross-section of the fuel bed was at *D*, 19 inches above the tuyères.

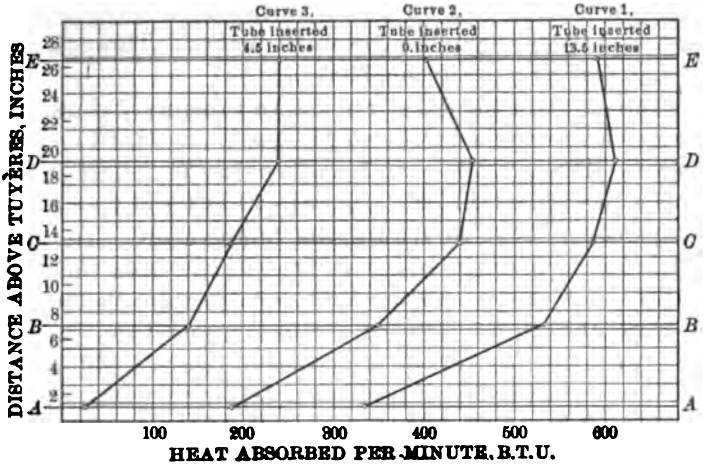

FIGURE 15.—Diagram showing variation in number of British thermal units absorbed at different heights (planes) in the fuel bed. Lines *A*, *B*, *C*, *D*, and *E* indicate the imaginary planes.

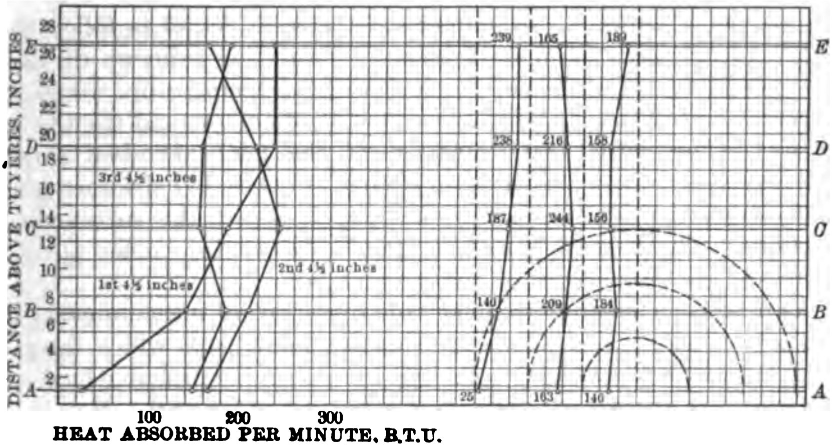

FIGURE 16.—Diagram showing variation in amount of heat absorbed per minute in different regions of cupola fuel bed.

EFFECT OF LOCATION.

The heat absorbed in each plane of the cupola is shown by the curves in figure 16. The figures representing the heat absorbed in the first 4½ inches from the lining are direct determinations.

The figures for the second 4½ inches are obtained by deducting the amount found for the first 4½ inches from the amount found for

9 inches, and for the third 4½ inches by subtracting the amount found for the 9 inches from the total for the whole 13½ inches. In the zone between the lining and a line 4½ inches within, the temperature increased rapidly through the lower 19 inches. Through the next 7½ inches it was practically unchanged.

A comparison with the gas curve shown in figure 7 shows that the temperature followed the increase of CO_2 to plane D, 19 inches above the tuyères. Through the next 7½ inches the CO_2 fell off though the temperature was constant, the amount of CO formed seemingly not absorbing enough heat to reduce the temperature. In the region included between lines 4½ and 9 inches distant from the lining the temperature increased to plane *C*, 13 inches above the tuyères and fell off from this point upward. This temperature curve, when compared with the gas curves presented in figure 6, shows that the increase of heat followed the increase of CO_2 up to plane *C;* then fell rapidly through the next two planes as the CO rose. In the third region, included between lines 9 and 13½ inches from the lining and representing the central part of the cupola, the temperature rose through the first 6 inches, fell off through the second 6 inches, remained constant through the next 6 inches, and finally increased rapidly through the last 7½ inches. Comparing this curve with the gas curves of figure 5, the temperature curve is found to follow the CO_2 curve through the first 12 inches. From this point up through the remaining 13½ inches of the fuel bed, the temperature would be expected to fall considerably since the CO_2 decreases and the CO increases. The actual determination of the heat absorbed shows the reverse to be true. The rapid change of CO_2 to CO absorbed heat and cooled the central part of the cupola below the surrounding portions. The flow of heat from the hotter to the cooler portion increased the temperature of this central part.

As it was not possible to make true temperature measurements at the several points corresponding with the points from which the gas samples were taken, it is not possible to confirm the probable location of the points of highest temperature as shown in figure 9. However, by the use of the curves shown in figure 15, it is possible to confirm the conclusion that the best melting zone is where the highest temperature and an absence of oxygen exist throughout the whole cross section of the fuel bed. An examination of the curves shows that the region of highest temperature corresponds with that region where oxygen is entirely absent across the whole cross section. This region is about 19 inches above the tuyères.

CONCLUSIONS.

The ideal melting region probably corresponds to that lying along and just above the line *ab* of figure 9. This line includes points in the figure representing those points in the cupola having highest carbon-dioxide content together with an absence of oxygen, as determined from analysis of the gases. It is manifestly impossible to confine melting to such a region, and the logical conclusion from the experiments here reported is that the best results are obtained if the iron is melted at that region in the cupola where the highest temperature, together with an absence of oxygen, exists across the whole fuel bed. The bottom of this region in the cupola tested was 19 inches above the tuyères when 1,000 cubic feet of air per minute was being blown. This region will be raised if the blast is increased and be lowered if the blast is reduced. Experimental determination of this region is not necessary. In practice, the bellying out of the lining of the cupola is a perfect index of the position of the melting zone, and this bellying is in the region where temperature is highest and oxygen is absent.

Care must be taken not to melt below the bottom of this region, for, the oxygen of the blast not being entirely removed, the iron will be oxidized or burned. The extent of this burning is dependent on the distance below the proper melting region and the lateral position in the fuel bed. Just below the bottom of this melting region oxygen is still found at the lining and the cross-sectional area of this oxidizing region increases as the distance downward increases until the whole cross section at the tuyères shows the presence of this damaging element. The whole problem of obtaining hot iron, free from effects due to oxygen, is solved by using small charges evenly distributed on the fuel bed,[a] and confining the melting to a few inches above the plane shown by the burning out of the lining to be the hottest plane of the fuel bed. If the first charge of iron is so placed that melting begins, say, 4 or 6 inches above this plane and is completed before any of the iron gets below it, and if the following coke and iron charges are so regulated as to maintain this melting zone, the best possible results will be obtained.

The experiments here reported indicate further that the use of upper tuyères is not only unnecessary but a positive detriment to the production of the best iron. The introduction of air into the fuel bed above the tuyères, even though in small volume, increases the liability of injurious effect from oxygen and serves no useful purpose. The increased tonnage supposed to be obtained by the use of upper tuyères can be produced just as easily by blowing through the bottom tuyères the proper volume of air.

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[a] Moldenke, Richard, The coke industry of the United States as related to the foundry. Bull. 3, Bureau of Mines, 1912, p. 22.

PUBLICATIONS ON FUEL TECHNOLOGY.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

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BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger, 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp., 4 pls.

BULLETIN 5. Washing and coking tests of coal at Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp.

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BULLETIN 24. Binders for coal briquets, by J. E. Mills. 56 pp. Reprint of United States Geological Survey Bulletin 343.

BULLETIN 27. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 44 pp., 3 pls. Reprint of United States Geological Survey Bulletin 366.

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Bulletin 55

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

THE COMMERCIAL TREND OF THE
PRODUCER-GAS POWER PLANT
IN THE UNITED STATES

BY

R. H. FERNALD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

First Edition, February, 1913

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THE COMMERCIAL TREND OF THE PRODUCER-GAS POWER PLANT IN THE UNITED STATES.

By R. H. FERNALD.

INTRODUCTION.

In investigating general problems that relate to the fuel resources of this country, and in testing fuels belonging to or for the use of the Government, the Bureau of Mines has given considerable attention to the efficiency and economic value of producer-gas power plants. Government inquiries during the past eight years not only have shown a very low fuel consumption per horsepower-hour for these plants but have demonstrated conclusively the possibility of utilizing commercially low grades of bituminous coal, lignite, and peat in plants properly designed for the use of these fuels. The anthracite plant has been recognized as a commercial possibility for several years, although the cost of the fuel used has in general restricted these plants to comparatively small units.

The commercial development of the producer-gas power plant in the United States has been largely within the past six or eight years. In 1909 the United States Geological Survey published in a bulletin[a] entitled "Recent Development of the Producer-Gas Power Plant in the United States" a list of producer-gas power-plant installations. The data presented in that bulletin showed a strong development in this field and led to much conjecture as to the future of this type of power. Owing to the extensive introduction of the steam turbine, however, many persons predicted the almost immediate doom of the producer-gas plant. In addition to the inroads made by this formidable rival, the interest of the gas-engine enthusiasts became centered to such an extent in the oil engine that the gas producer was relegated to second place by many and absolutely abandoned by some. During the past three years the belief of many who were formerly firm believers in the gas producer has been that this type of power has reached its height of development in this country and that from a commercial standpoint it can no longer be regarded as a complete success. This feeling of commercial decadence has become so general that the facts gleaned from an inspection of the summaries and charts presented in this bulletin will undoubtedly surprise those who have regarded the immediate downfall of the producer as inevitable.

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[a] Fernald, R. H., Recent development of the producer-gas power plant in the United States, U. S. Geol. Survey Bull. 416, 1909, 82 pp. Reprinted as Bull. 9, Bureau of Mines.

In 1909 the estimated horsepower of gas and of oil engines installed for industrial purposes in the United States was 800,000, as reported by Louis B. Stillwell.[a]

It is hardly possible to arrive at a correct estimate of the total gas-engine horsepower in the world at the present time, but excluding automobile engines, 8,000,000 horsepower is perhaps a conservative estimate. Possibly 2,000,000 to 2,500,000 horsepower of gas engines, large sizes mainly, is derived from the waste gases of blast furnaces; the remainder is derived from illuminating gas, natural gas, producer gas, and the various liquid fuels.

In considering the above estimates it is of interest to note the figures presented on another page which show that in the United States gas engines, with an aggregate capacity of about 200,000 horsepower, derive their power from producer gas, and that with an aggregate rating of 350,000 horsepower or more derive their power from blast-furnace and coke-oven gas.

ACKNOWLEDGMENT.

The preparation of this bulletin has been made possible only through the hearty cooperation of the manufacturers of producer-gas and blast-furnace gas equipment and of the steel companies. Acknowledgment is hereby made of the generous response to the request for lists of installations and of the courteous consideration given to the many queries put to those who have furnished the accômpanying information.

VIEWS OF MANUFACTURERS OF PRODUCER-GAS POWER PLANTS.

An effort has been made during the past six years to follow with some degree of accuracy the commercial trend of the development of the producer-gas power plant. To do this satisfactorily it is important to know the point of view of both the manufacturer and the owner of such a plant. The following question was, therefore, addressed to several manufacturers of gas producers in 1906, in 1909, and again in 1912:

> To what extent is the demand for gas engines and gas producers and the interest in the same growing?

The replies received in 1906 embraced the following:

1. We believe there is a waiting and almost unlimited demand for producer power plants as soon as the manufacturers have something definite to offer and can guarantee quick installation and certain results.

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[a] "Electricity and the Conservation of Energy," address delivered in New York City, March 24, 1909, at a meeting for discussing conservation of natural resources.

2. The demand for gas engines and gas producers is growing considerably. We have this month closed for an 8,000-horsepower gas-producer plant, and have on our book negotiations pending for over 200,000 horsepower.

3. The demand for gas engines and gas producers is at present seemingly limited only by the output, we ourselves having orders way ahead and all the business we can possibly fill. Were we to go out after business we would immediately swamp the factory. These plants are giving such excellent results in the field that they are bound to replace steam for almost all uses, and in consequence the field may be said to be almost unlimited.

4. The demand for gas producers and the interest manifested in them seems to be growing very rapidly, as indicated by the number of inquiries received at our office and by our agents in different parts of the country.

5. According to inquiries which we are constantly receiving we judge that the interest in the question of gas producers and gas engines is growing considerably, and all indications lead us to believe that the proposition to install gas-power plants will be a very important one in this country before long.

6. Our correspondence indicates a continually growing demand for gas producers for power purposes, especially those adapted for running on soft coals.

7. There has probably never been a mechanical production more widely or thoroughly advertised at such an early period of its history in this country as the suction producer-gas power equipment. Much of this advertising has aroused curiosity among people, many of whom are not contemplating a purchase. On the other hand, the fuel economy is so remarkable that manufacturers with a reputation for reliable goods and with the fuel guaranties they offer, backed by unquestioned responsibility, are able to sell their product with very little effort.

8. The gas-producer business and the uses to which they have been applied have increased about 50 per cent within the past 10 years, and are still growing. We should imagine that the next 10 years would show a far greater improvement. We think producer gas is yet in its infancy as to various applications.

9. The demand for gas engines and gas producers is growing in that field where the price of coal is highest, and for that reason any commercial tests in suitable gas producers that will use the fuel of the district will be of value.

10. There is no doubt that the gas engine itself is nowadays in such a state of perfection that its use is bound to become general for power production as soon as the possibility of using bituminous coal to a large extent has been proved.

The manufacturers' feeling of assured success of the producer-gas power plant and its brilliant future was again strongly affirmed in the replies for 1909, including the following:

1. It is quite certain that not only the interest in producer-gas power in this country is still growing, but the actual plants being installed are very markedly increasing both in number and size and variety of service. This has resulted in a great stimulus for this type of producer plant by some of the largest and most conservative users of power in the country, such as the public-service corporations.

2. Our experience is that the demand for gas engines and gas producers is showing a logical growth. In the small and medium sized plants the particularly high efficiency compared with steam-plant operation makes the field for this class of apparatus very large, and a great deal of it is being bought. In large plants, involving the use of units say above 500 kilowatts, the general economic superiority of plants of this class is not so heavy, although there are special cases where large gas engines are of great economic value.

3. There is a decided growth when used for power purposes only and where factory heating is not an essential factor, also where producer gas is used for furnace purposes. Producer gas is rapidly being adopted for power and fuel purposes, while steam is usually installed (at present prices of coal) for power and heating.

4. We find the demand for gas engines increasing very rapidly, having sold more engines since the first of the year than we had in any two years previous. Our shop at present is well filled with orders. The inquiries for producer plants are coming in very rapidly since the gas producer has been brought up to its present state of perfection.

5. It appears that the demand for equipment of this character has kept up in spite of the recent financial depression and business reaction. This should be interpreted as an increase in the interest in the fuel ecomony usually obtainable in this class of machines.

6. Strongly. Can take orders in only one or two sizes for anything under eight months' delivery.

7. We believe that the demand for gas engines and gas producers is considerably increased, both in the large and small installations. This is evidenced by the fact that there are a number of builders of good anthracite suction producers who find considerable business in the small units, while we have received many duplicate orders for additional units, showing the tendency is to favor the gas producer and gas engine in central power plant work.

8. From inquiries we are daily receiving for producer-gas power plants, it certainly looks as though power users are beginning to realize the advantages in a producer-gas plant, and our opinion is that the producer is going to make a very rapid stride within a year or so.

9. By the inquiries received by us and the requests for information and for quotations, on power equipment, as well as by sales actually made, we should judge that the interest and demand for gas engines and gas producers is growing very rapidly. There is further an inclination on the part of the larger power users to consider this type of prime mover that was not apparent two or three years ago. Formerly the majority of our inquiries were for producers ranging from 25 to 100 horsepower capacity. This year's business has been made up very largely of producer equipment ranging from 200 horsepower upward. We take this as an indication that considerable of the doubt previously entertained by the general public as to the reliability of producer-gas equipment has been eliminated, and that power users are having increased confidence in this sort of equipment.

10. The general interest in gas engines and producer-gas power plants is constantly growing, judging from the increasing number of inquiries which we have been receiving during the past year regarding this type of apparatus. This interest is aroused, doubtless, by the advertising of gas-engine builders and the large number of articles written. We believe that the demand for gas engines and producers is growing likewise, as more and more of them are installed for all classes of service, and their reliability and economy under actual working conditions are proved after several years of operation. We do not, however, believe, as some manufacturers seem to, that the gas power plant is bound to replace nearly every steam installation. Local conditions often make it considerably cheaper to install a noncondensing Corliss engine rather than a gas engine. Considerable difficulty is also experienced in obtaining competent gas-engine operators for anything like a reasonable salary, owing to the newness of the gas-engine field.

In 1912, however, the effect of the development of the oil engine shows conspicuously in several of the following statements from manufacturers:

1. The demand for gas engines and gas producers has extended to nearly every variety of service to which power can be applied, and the inquiries for this type of equipment continue to increase each year.

2. We are pleased to note the tendency to install gas-producer power plants of considerable capacity. In fact, nearly all of the business we now have in sight is for plants of 300 horsepower or larger.

3. We believe that there is a constant demand for gas producers and gas engines, especially in the smaller powers. We have not had a great many inquiries for large plants, but this is perhaps in a measure due to the period of business depression that has existed for the past three years, which has been a factor against the financing of large power installations. Then there is also the competition of the reciprocating steam engine in combination with low-pressure turbines.

4. That there are certain well-defined fields, limited chiefly by labor, fuel, and water costs, in which gas power proves to be the only practical solution, is now generally appreciated, and in these fields there appears to be a constantly increasing demand for engines and producers.

5. The demand for gas engines and gas producers for the present, at least, is not increasing. In fact, since the advent of the lower grades of oil as a fuel for internal-combustion gas engines, there has been a marked decrease in the sales of producer-gas engines and gas producers.

6. There is a steady increase in the demand, but not as rapid a growth in the business as should be looked for when the saving due to economy is considered.

7. We have not been very active in hunting up business in this line. It developed that with our shop equipment we were not in a position to build gas engines to advantage. It has also been developed that other lines were more attractive to us; consequently our efforts have been in other directions. We doubt if we shall resume the building of gas engines and producers, because to do so to advantage would require the investment of additional capital, which we believe can be employed to better advantage in other lines.

8. We have not much to say regarding the development and present status of this type of plant in the United States, except that there have not been many inquiries in the past year, and as you will observe from the list, there have not been many new installations.

9. The demand for gas engines and gas producers is not growing as fast as it should. Interest appears to be increasing, but as yet has not grown into a demand.

10. Although there has been a fair demand for producer-gas installations, the recent development of the oil engine, using crude oil, fuel oil, and similar heavy fuels, has no doubt had its effect in preventing the placing of a larger number of producer plants, especially in localities where the heavy liquids can be obtained at low prices.

11. Demand for reliable bituminous producer-gas power plants is increasing steadily, though not rapidly, under the following circumstances:

(*a*) When large power users are willing to invest in new equipment on a basis of a net saving of 10 per cent on the investment.

(*b*) If the cost of coal is above $2.50 per ton and if crude oil costs over $1 per barrel.

(*c*) If low-grade fuel, such as peat and lignite, which is not satisfactory for firing boilers, but suitable for gas producers, can be obtained at low cost.

12. The development of the steam turbine seems to have temporarily outstripped the gas engine and gas producer for large units, as uniformly satisfactory results can not yet be universally obtained and maintained with the latter.

13. At the present time the demand for producer-gas engines and gas producers for power in the United States is to some extent overshadowed by the enthusiasm about the Diesel oil engine. In the mind of the ordinary purchaser at least, this engine or some other form of fuel-oil engine is more satisfactory and economical than a suction-producer plant burning anthracite. This contention is in some cases correct. There is, however, an increasing demand for tolerably successful producers to operate on bituminous coal, and we believe that the advent of this type of apparatus will do much to regain the ground that has momentarily been lost to the oil engine.

14. Very slowly but steadily in the Eastern States the producer plant is living down the effect of many poor installations made three to five years ago, also the effect of many failures due to incompetent operators.

15. In this connection we might call your attention to the fact that we do not push the gas-engine business very strenuously because the larger number of inquiries are for oil engines and the latter type seems to meet conditions far better than do the gas engines.

With the preceding expressions of the manufacturers in mind, it is worth while to examine figure 1, which shows the remarkable development of the producer-gas power plant for the past 12 years. The diagrams are, of course, made up from an exact list of installations reported by the manufacturers (p. 31). Inasmuch as it was impossible to procure a complete list of installations from some manufacturers and as no information was received from a few others, the figures presented probably represent not over 75 or 80 per cent of the plants actually installed.

When the first inquiry was sent out the manufacturers were also asked:

What are the serious difficulties in the way of more rapid development of gas producers and gas engines as a means of developing power?

A summary of the replies received in 1906 would indicate the difficulties, as viewed by the manufacturers at that time, to have been about as follows:

1. The fact that the gas engine is not yet so reliable as the steam engine.
2. The lack of engineers who know how to run producer-gas power plants.
3. Inexperienced salesmen—men not familiar with the details of the engines and producers they are handling.
4. The large number of unsuccessful and only partly successful installations made during the experimental period of this development.
5. Lack of proper design and construction of producer-gas engines in the United States.
6. Lack of knowledge and confidence on the part of the public.
7. The fact that the heating of factory buildings must be provided for by a heating plant separate from the power plant.
8. Lack of types of producers that will gasify bituminous coal satisfactorily.
9. Inability to use cheap fuels in the suction gas producer.
10. Lack of complete knowledge as to how successfully the various fuels in different localities can be used in gas systems.
11. Large excess cost of gas-engine and gas-producer power plants over that of steam power plants.

The difficulties in 1909 were expressed as follows by the manufacturers in replies received from them:

1. Skepticism as to the reliability of gas engines and producers, one-half of the skeptics being against the producer and the other against the engine.
2. Large engines of long stroke become disproportionately high in price, and in the very large installations their availability is not so evident unless fuel is very expensive. Furthermore, the absence of large overload capacity detracts from the flexibility of operation so commonly experienced with steam plants, which may be forced from 50 per cent to 100 per cent above rating. The gas engine and the producer have their particular application and are not a universal panacea for all our previous ills.
3. Lack of confidence in either producer or engine, due to minor defects in each, which makers do not rectify after plants are sold.

4. The chief drawback to the suction hard-coal producer development seems to be the failure of some installations, due not to any faulty construction and design, but to the disinclination on the part of the attendant to properly operate the plant or to learn how to do so. A satisfactory suction soft-coal producer would be a great boon to the gas engine and producer business. The tar, of course, is the main trouble in this case.

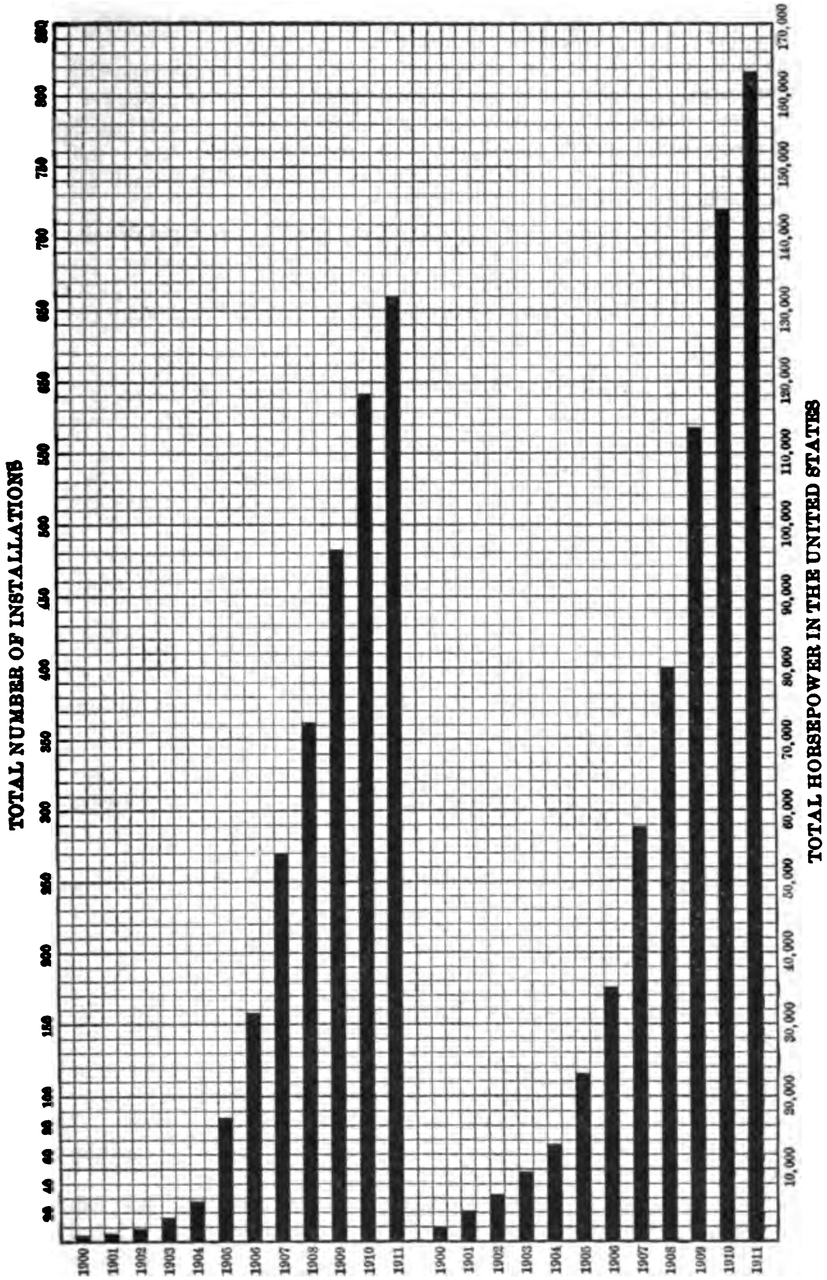

FIGURE 1.—Installations and horsepower of producer-gas power plants in the United States, 1900–1911.

5. None—except education of the general public.

6. The most serious difficulty is the constant entering of new manufacturers into the field. These very often lack the experience necessary to build apparatus that will insure successful operation in central power plant work. We believe it is the size of unit more than anything else.

7. The fact that the average producer builders rate their producers too high, and are not able to instruct their customers to operate the plant properly.

8. The most serious trouble lies in the difficulty of educating the general public, and more particularly engineers to whose hands the laying out of gas-power equipment is usually intrusted, to appreciate fully the requirements of such installations. Most failures are due to lack of appreciation on the part of manufacturers, as well as on the part of power users and consulting engineers, of the importance of small details of the general arrangement of the plant.

9. To our mind, the most serious difficulty in the way of more rapid development of the producer-gas power plant is the difficulty in obtaining a satisfactory producer which will use practically all grades of American bituminous coal, and which at the same time will not be much more expensive than the ordinary anthracite producer plant.

10. The summary of replies (for 1906) very nearly expresses the condition as to the gas producer at the present time, though I would say relative to the engine itself, the record of the engine which we have and its running indicate trouble only with the producer of the electrical outfit during the last three or four months.

Summary No. 7 (for 1906) is to my mind the greatest lack that we have in the introduction of the producer-gas engine. I do not doubt but that this could easily be taken care of, if it has not been up to the present time.

In regard to No. 8 (for 1906), we have not tried bituminous producers and therefore have not had the trouble with the gas washing, but we can not use cheap fuels. as we had anticipated we could.

The large cost referred to in No. 11 (for 1906) is to-day in the same condition, but I do not believe that the high selling cost is warranted by the shop costs.

The views of the manufacturers in 1912 regarding these difficulties are as follows:

1. The gas producer evidently received a setback several years ago from which it has not yet recovered. To overcome the lack of confidence as to the efficiency and reliability of gas producers is a great difficulty in the way of more rapid development.

2. General prejudice due to failure of plants installed by inexperienced manufacturers.

3. Active campaign against gas engines by steam-engine and oil-engine manufacturers and by hydro-electric companies.

4. Lack of capital to invest for new equipment.

5. Lack of familiarity with producer-gas plants among consulting engineers upon whom power-plant owners depend for expert advice.

6. High first cost of a producer-gas plant compared with that of a steam plant.

7. Lack of cooperation between engine builder and producer builder.

8. We are still waiting for the advent of the "fool-proof" soft-coal producer. When it comes it will be mechanically agitated; it will be simple, and the tar will be converted into gas in the producer.

9. Two difficulties stand in the way of more rapid development of the gas producers and gas engines: First, there are very few satisfactory producer-gas engines built in the United States. The great majority of engines marketed as such are not at all fitted to this service; second, the growing difficulty of procuring anthracite makes the handling of bituminous coal imperative. It is essential that the bituminous

coal should be handled without the production of objectionable by-products, that the gas should be clean, and that the labor required to handle the plant should be small. There is much skepticism in the mind of the purchaser as to the possibility of meeting these conditions, and this, of course, is interferring to some extent with the more rapid development of producer-gas power.

10. The present difficulty in the way of more rapid development of the gas-producer business is the low price at which can be obtained oils which will give very nearly the same fuel cost as for the gas-producer outfit and involves a much less initial installation cost.

11. A strong fight is being made by its natural opponents. The central-station power salesmen, as a result of more or less organization, are well posted in regard to all failures and make good use of their information. The consulting engineer will take no chances in advising a new type of plant, since the cost of operation concerns him little. Lack of efficiency of the gages, indicators, etc., which might locate trouble or unfavorable conditions in the system. These defects are rapidly being developed. Many failures have been due to imperfect scrubbing of the gas.

12. Regarding the serious difficulties in the way of more rapid development of producers and engines, we do not recognize any. There appear to be mechanical limitations to the development of this type of prime mover in sizes exceeding 1,000 brake horsepower in any one double-acting four-cycle cylinder. In the two-cycle type it is probably possible to double this capacity.

13. To the writer's mind one of the most serious difficulties in the way of rapid development of gas producers is the development of an apparatus that will readily gasify any and all fuels and will stand up under severe overload. Although it is possible to build large units that will take care of certain fuel requirements, we find that there is a tendency on the part of the owners to force apparatus of this kind while using fuels of a much lower grade than originally specified, with a result that the apparatus does not stand up and is condemned. There seems to be a constant tendency on the part of engineers and operators to attempt to treat a gas plant in the matter of overloads in the same way as a steam plant is treated, and in the present state of the art, unless the plant is built with excessive capacity and consequent high first cost, it is soon put out of commission. There seems to be a demand for a gas producer that will stand 100 per cent overload for an indefinite period, and under these conditions will run on bituminous fuels containing 15 to 20 per cent ash. The attempt to meet conditions like the above has made trouble for purchasers as well as manufacturers, and some manufacturers have not fully realized that special requirements demand special installations and that it is impossible to make a standard gas apparatus that will handle every grade of bituminous coal with equal ease and efficiency.

14. We believe the difficulty to be high first cost of a complete plant when well constructed, so as to give satisfaction, and the retarding effect of cheap-plant failures.

PRESENT STATUS OF THE PRODUCER-GAS POWER PLANT.

The foregoing expressions of the manufacturers of producer-gas power plants may be summarized thus: Their attitude in 1906 was very optimistic, and their position in 1909 was extremely gratifying. Their fair-mindedness, their appreciation of the difficulties involved, and their realization of the shortcomings of the producer-gas power plant in 1909 all pointed directly toward the development of highly efficient gas-power units using many types of fuel and involving a total cost of installation that would compare favorably with that of the corresponding steam plant and at the same time insure the manufacturer a fair profit. Although in the past three years there has been a steady and gratifying continuation of producer-gas power-plant activity, yet the recent letters of some of the manufacturers seem to show an attitude of uncertainty or expectancy. For this attitude there seem to be two causes—one the hope for a marked development in the bituminous gas producer and the other a feeling of doubt, due seemingly to oil-engine activities.[a] Although there may be some foundation for this reduction in the enthusiasm on the part of the manufacturers, yet they will do well to study the table on page 65, which shows that the number of producer-gas power plants installed during the past three years amounts to 52 per cent of the total number installed during the preceding nine years. Inasmuch as additions to plants previously installed are not listed in this table, it should be further stated that the number of producer-gas power units sold during the past three years amounts to nearly 70 per cent of the number installed during the preceding nine years.

Further examination of the table will show that the horsepower represented by the installations made during the past three years amounts to 68 per cent of the total horsepower installed during the preceding nine years.

So much has been written regarding the difficulties met in producer-gas power-plant practice and these difficulties have been so constantly thrust before the public that it is desirable to study carefully the true situation regarding the many charges that have been laid at the door of this particular type of equipment.

A review[b] of the statements as to the difficulties enumerated in the pages following will show how rapidly most of these difficulties are being dissipated.

RELIABILITY.

1. The fact that the gas-engine plant is not so reliable as the steam-engine plant.

An examination of the replies received from the manufacturers in 1909 shows that only 2 out of 10 regarded this point as vital, and 1 of these felt that the difficulty was with the public rather than with the plants themselves.

Abundant testimony may be obtained from owners and operators of these plants regarding the reliability of such installations when properly handled. It is not proposed to reduce this discussion to a series of testimonials, but it seems consistent to report the statements of the owners of a few gas-power installations.

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[a] Since the above was written, the development of producer-gas plants has received a marked impetus owing to the increase in the price of oil and the impossibility, in many cases, of procuring long-time oil contracts.

[b] Much of the material cited appeared in U. S. Geol. Survey Bull. 416, reprinted as Bull. 9, Bureau of Mines, as mentioned in the introduction of this report.

It was the original intention to publish the letters in full over the names of the authors, but inasmuch as some of the comments might be interpreted as promoting the interests of certain manufacturers to a greater extent than those of others, it is deemed wise to present the substance of the communications without reference to the particular plant in question.

These statements in 1909 were as follows:

(*a*) I have a 75-horsepower producer-gas engine and producer. I have always found it reliable and a very economical source of power. The net result of its operation, based on a 10-days' test, gave me 1 horsepower for every 1.05 pounds of coal burned per hour. In average practice, however, I believe the consumption of fuel would be slightly higher, but I do not believe it would be in excess of 1.15 pounds per horsepower-hour.

I wish to say further that I am lighting my house and stable with a 15-horsepower producer-gas plant, with an average run of 5 hours a day and an average load of 50 16-candlepower lamps, and my total consumption of fuel for the 24 hours, including 5 hours' run, will average 100 pounds. This coal costs me one-quarter of a cent a pound delivered. My lubricating-oil expense is very low, as the engine is a crank-case splash, and I have only one lubricating cup on the engine to oil the journals of a small shaft.

I do not figure my time as anything, as the man who attends to this plant is regularly employed by me doing other work on my place. All the attention he has to give it is about half an hour a day, and the engine runs entirely without any supervision during the evening.

(*b*) In January, 1907, ——— Co. installed for us a producer-gas power plant consisting of three 50-horsepower horizontal gas engines, two of which are direct connected, making a unit of 100 horsepower, and attached direct to a generator. The other engine is a separate unit with its own generator attached. We have two gas producers, one of 100-horsepower capacity and the other of 50-horsepower capacity.

We have used this plant continuously since its installation and with satisfaction, furnishing to our plant current which is distributed throughout the works to many motors, besides furnishing light and power for one large freight and one passenger elevator.

We do not use the full capacity of the plant, holding at all times the separate unit of 50 horsepower in reserve.

The cost for the calendar year 1908 was as follows:

Coal	$538.25
Oil	49.20
Waste	11.52
Removal of ashes	18.00
Water	168.00
Gas	50.06
Attendance	581.92
Maintenance repairs	492.78
Insurance	148.68
Lamp renewals	66.70
	2,125.11

Our kilowatt hours used during the entire period amounted to 134,063, making net cost to us 1.585 cents per kilowatt hour.

Previous to the installation of the plant we employed a fireman to take care of the steam-heating plant, and our charge for attendance in the foregoing statement is the amount paid in excess of what we had previously paid for attendance on our steam-heating plant. We are obliged to keep steam up the year around, as we use it for several purposes in our factory, and the charge under attendance, therefore, is proper but less than would follow under other conditions.

(*c*) We have two gas-engine plants using producer gas. The first station has two 600-horsepower four-cycle gas engines, operated by a pair of down-draft soft-coal producers. The other plant has three 500-horsepower two-cycle double-acting engines, operated by five pressure hard-coal producers. The first plant named has given both the best economy and the best service, and this plant has been in every way as reliable as a first-class steam plant. The second plant named has not proved so efficient, but has been equally reliable.

(*d*) This plant was installed in the spring of 1906 and consists of a suction gas producer of size to furnish sufficient gas to generate 70 horsepower; a 65-horsepower single-cylinder heavy-duty engine; and a 13 by 12 single-acting outside-packed plunger triplex pump.

It may be well to say that the plant is giving entire satisfaction, the items of reliability and economy, both of which depend so largely upon the experience of the operator, being all that could be desired.

In an article subsequently published by the writer of the above, after describing numerous experiences with the plant during the early days, he goes on to say:

The results obtained from the plant are most satisfactory. Our longest continuous run to date was made from 5.15 a. m. November 24 to 1.50 a. m. December 4, 1907, 235¾ hours. The plant has been in operation since November 2 and the stop was made for the purpose of cleaning the mixing valve and changing igniters, which occupied 2 hours. This was not planned in any way as a record run. Our engineer assures me that it was not absolutely necessary to stop when he did, but we had shortly before this been troubled with dirty gas, and we were curious to note what effect, if any, had been produced by increasing the amount of shavings in the cleaner. Much to our satisfaction it had proved to be of great benefit.

Our plant is now running 24 hours a day, and we are pumping 1¼ million gallons with a coal consumption of 1,100 pounds. The record for yesterday was 62,440 revolutions; the total head, including suction lift, was 108.4 feet; coal fired, 1,085 pounds. This gives a duty of 107.6 million foot-pounds per 100 pounds of coal.

* * * * * * *

During the test of the producer-gas plant its duty per 100 pounds of coal fired exceeded 135,000,000 gallons.

I desire to call your attention to the fact that we are pumping against only 110 feet total head, whereas the unit is designed to work against from 160 to 170 feet total head, which it did during the test above mentioned; also to say that while the engine is now running under a little more than half load, the duty would be materially increased were it running up to rated capacity.

A letter relating to an installation of several thousand horsepower operating for several years on bituminous coal states:

(*e*) Although during the first of our experiences with this method of power production we had some difficulties, it can be fairly said that they were chiefly due to ignorance on our part, and that under the conditions as they are to-day the plant is running as steadily and with as great a factor of reliability as we have ever experienced with steam.

(*f*) We installed a suction gas producer of 60 horsepower and a 25-horsepower gas engine about three and one-half years ago. During this time we have never had any trouble of any kind with said installation, nor have we spent $5 for repairs.

We have cleaned the scrubber once since the plant was installed, and the fire in the producer has not been taken out for very nearly a year's time.

We must state that we are very much pleased with said producer and gas engine and should we be compelled to increase the present power system, we should certainly install just the same as we are now using.

In connection with the above beg to inform you that we average about 22 horsepower and run our engine 9½ hours each day, 6 days each week, using but 1 ton of No. 2 nut coal at the cost of $4.25 per ton.

(*g*) The plant contains a 500 brake-horsepower horizontal four-cycle double-acting engine with a 300-kilowatt direct generator and a bituminous gas-generating unit of the intermittent type. The producer plant consists of two 250-horsepower downdraft generators with auxiliaries.

Our figures show that we can produce a brake horsepower per year with the gas plant for $30. With the old steam plant it cost us $45. This is for 10 hours a day for approximately 300 working days a year. These figures include coal, labor, supplies, interest on investment, and depreciation of plant.

The plant has given us no more trouble than a steam plant of the same size. Our log shows that from January 1, 1907, to date (February, 1908) we have shut down only 34 minutes, this being due to ignition troubles once, poor gas once, and an obstructed cooling pipe once.

This plant is not offensive to the neighborhood, and noise from the exhaust is no more than from a steam engine of the same capacity. * * *

No trouble is occasioned in starting, it being possible to be up to full speed in as short a time as one-half minute, the usual method of starting being to run on air for six or eight revolutions before turning on the gas.

In general, from our experience with this plant, we believe it to be both economical and dependable.

A letter received June 23, 1909, from the company owning this plant, states that since the article was written (February, 1908) from which the above abstract is taken, "The plant has given us entire satisfaction".

By reference to the observations relating to the plants that have been personally inspected (pp. 36–57) many cases of exceptional reliability and economy may be noted. Attention should be called to plant 57, in which the fire has not been drawn from the producer for over seven years.

In connection with the experimental work of the Government fuel-testing plants the opportunity for endurance runs was decidedly small, owing to the fact that the supply of any one grade of fuel was sufficient only for a run of approximately 60 hours. The plant was operated week in and week out 120 hours a week, the engine running the full time, but the necessity of changing fuels after each 60-hour run made it imperative that two gas producers be used. In the spring of 1905 one supply of Illinois bituminous coal delivered at the St. Louis testing station was sufficient for continuous operation for several days. The test began March 8 and continued without interruption until April 1—24 consecutive days. During the entire time the engine showed no signs of heating, clogging with tar, or other trouble. It ran steadily at all times and at the end of the test was in perfect condition. The same set of igniters was used throughout the run, and gave absolutely no trouble. An inspection of the engine at the close of the test showed that the cylinders, igniters, and all working parts were in such excellent condition that the engine was not even cleaned nor its mechanism in any way changed before beginning the next test. An inspection of the producer plant at the close of the test also showed that everything was in a correspondingly good condition and the regular tests went on as usual after the close of the endurance run.

In connection with the tests made at Norfolk the samples of coal for testing purposes were sufficiently large to warrant longer runs than the regular testing period at St. Louis.

An abstract from the log of these tests is as follows:

Test 164: 144 hours' duration. Interrupted for a few minutes when an indicator-rig wire fell across an igniter circuit.

Test 165: 240 hours' duration. Uninterrupted.

Test 166: 213½ hours' duration. Shut down of 2¾ hours because of a short circuit in igniter which was troublesome to locate.

Test 167: 44 hours' duration. Uninterrupted. Reason for short test was the desire to study the effect of a shutdown for a period of 36 hours, after which the test was continued as No. 168.

Test 168: 240 hours' duration. Uninterrupted.

LACK OF ENGINEERS.

2. The lack of engineers who know how to run producer-gas power plants.

My comment upon this situation in 1906 was:

It can not be denied that many of the difficulties charged to producer-gas power plants are due entirely to incompetent operators. Some plants have been put out of commission temporarily by the prejudices or the lack of ability and training of the operators or engineers in charge. A few of these failures are due to the impossibility of finding men competent to operate the plants, but many of them have undoubtedly been the result of a short-sighted policy on the part of some manufacturers, who are not willing to give proper and necessary information about the design, construction, and operation of the plants made by them. The possibility of a sale at the time is apparently the only interest they keep in mind, and the future is allowed to take care of itself.

In 1909 the following discussion of the comment made above was published:

Although of necessity the comment of 1906 still holds to a certain extent, yet it is certainly true that conditions have greatly improved within the time indicated. There are at present many operators competent to take charge of the plants, but there are also many attempting to operate gas installations who are not in the least fitted for the work.

The attitude of the manufacturers as a whole has materially changed. The distrust and jealousies that have characterized the dealings of some in the not distant past are gradually disappearing, and on the whole to-day the manufacturers seem ready to render all the assistance possible in connection with the proper manipulation of their installations. There is, however, still room for improvement, and the indications are in the right direction when the manufacturers themselves recognize these faults, as is shown by their own statements. (See items 7 and 8, p. 12.)

Many of the difficulties due to lack of knowledge of their own plants, improper design, faulty construction, impossible contracts, and failure to render reasonable assistance in putting up and starting new installations have been due in part to undesirable competition and jealously on the part of certain manufacturers. Within the past two years the varied interests working for the development of gas power have been brought more closely into touch through friendly organizations, with the result that a better understanding and a heartier cooperation is beginning to prevail. Notable among the organizations that are tending to unite these many interests on a common basis is the gas-power section of the American Society of Mechanical Engineers.

A condensed summary of the views manufacturers expressed in 1912 regarding reliability is as follows:

1. The design of engines and producers, especially of producers, is being simplified and consequently made more reliable.
2. There should be no reason why a gas-producer power plant should not be just as reliable as any other type of prime mover, if the proper precaution is taken to install equipment that will exactly suit the conditions of operation.
3. We believe that the gas-producer plant, intelligently operated, and with cleaning, upkeep, etc., systematized, is just as reliable as a similar steam plant.
4. Reliability of producer-gas plants is very good when plants are competently installed. Care and attention are not excessive if intelligent and given at the right time.
5. Gas-power machinery having only within the last few years reached a degree of standardization comparable to that of the steam engine, it is natural that operating difficulties should be expected, except in the more recent installations. It would appear that difficulties of this kind are at present practically eliminated, and that in the case of carefully executed designs properly operated the reliability of the gas engine is above question.
6. Producer-gas power plants using commercial bituminous coal are dependable for continuous full-load operation. Proper attention to conditions existing at the plant will insure this.
7. With a good producer-gas engine and a good producer, reliability is seldom questioned.

The manufacturers in 1912 expressed the following opinions:

1. We find a steady increase in the number of competent engineers available.
2. The lack of competent operating engineers has made itself felt in many instances, and at this writing calls for competent operators, which we are unable to fill, are made on us.
3. We believe that it is now possible to obtain competent operating engineers provided manufacturers are willing to pay them a fair salary.
4. The successful operation of a producer plant depends principally upon three things: First, a properly designed engine and producer; second, the right kind of coal; third, an intelligent engineer. We find that the good qualities in engineers are not always found in a high-priced man, but are more dependent upon the interest taken by the man in charge.
5. It will probably always be true that more intelligent attendance is required for this type of apparatus in any appreciable size than is necessary for a steam plant.
6. Operating engineers must be competent. The public has been told too long that anyone can run a gas producer and that the gas engine is "fool proof."
7. A competent steam engineer can operate a gas engine after a few weeks' experience. All of our plants are operated by men without previous gas-engine experience. Producer firemen are no more expensive than boiler firemen.
8. There is no great lack of competent operating engineers, but this may be due to the fact that there is a strong tendency to provide the producer plant with the same aids and facilities for operating that are commonly provided for steam plants.

INEXPERIENCED SALESMEN.

3. Inexperienced salesmen—men not familiar with the details of the engines and producers they are handling.

Writing in 1909 the author said:

A few years ago would-be purchasers had to deal with ignorant and often unscrupulous salesmen. Except possibly in a very few insignificant companies, the unscrupulous agent seems to be rapidly dropping into the background. Incompetent and uninformed salesmen will always be with us, but the situation to-day in this respect is greatly improved over that of three years ago.

The manufacturers in 1912 make the following observations:

1. A producer-gas engineer should get on the ground and lay out each plant.
2. It has come to our attention in a number of instances that salesmen who have been totally unfamiliar with the requisites of a successful producer installation have misled prospective customers in the belief that no matter what the customer requires in the way of a power plant, a producer plant gives the best satisfaction. It often happens that such is not the case.
3. We do not believe there is as much trouble to be charged to inexperienced salesmen as to unscrupulous salesmen.
4. There is no doubt but that much dissatisfaction is caused because of the salesman's lack of experience, the result being equipment not suited to the work to be done.
5. Inexperienced salesmen are gradually disappearing. Every producer and gas-engine contract should have the careful attention of a competent engineering department before being approved.
6. Inexperienced salesmen are not as troublesome now as heretofore.

UNSUCCESSFUL INSTALLATIONS.

4. The large number of unsuccessful and only partly successful installations made during the experimental period of this development.

For reliable companies presenting their standard plants, this situation is a thing of the past. However, certain new companies in the field and also new types of producers, which are constantly appearing, feel its effect.

The manufacturers in 1912 state:

1. We have remodeled into very successful installations two unsuccessful ones placed by other firms.
2. In the several cases of unsuccessful installations that have come to our attention the trouble has been traced to improper equipment for the specific conditions, and also to incompetent operators.
3. There is naturally considerable trouble from unsuccessful installations. Some of the installations are justifiably unsuccessful, because they could never give the results guaranteed by the firm installing them; some are unsuccessful because the operators are underpaid and are therefore incompetent and do not know or care to know anything about the apparatus they handle; some are unsuccessful because of overloading and operation on fuels that the plants were never designed to handle; some are unsuccessful due to causes not in any way chargeable to the installation as a gas plant. For instance, the writer knows of one installation that has been taken out, because it was located on ground that was particularly susceptible to vibrations, the vibrations caused by the operation of the gas engines being transmitted a long distance and being severe enough to jar crockery from the shelves in dwelling houses. Here we

have a black eye for the gas-power industry not caused by anything that could be clearly foreseeen.

4. Unsuccessful installations are undoubtedly a serious obstruction to more rapid progress.

5. One installation that is successful is seldom heard of, but one that fails is heard of everywhere.

DESIGN AND CONSTRUCTION.

5. Lack of proper design and construction of producer-gas engines in the United States.

The situation in 1909 in this respect was the same as is encountered in the purchase of nearly all manufactured articles. There were reliable companies offering a well-tried first-class article, whereas others were advertising equipment that resembled the first only in external appearance and in the fact that it, too, was labeled "gas engine" in the catalogues. Too much care can not be exercised in the selection of the proper equipment for producer-gas power plants. The assumption that one make is just as good as any other and that consequently the one to purchase is the one offered at the lowest price is leading to many regrets.

The replies from manufacturers in 1912 contained the following statements:

1. There has been too much theory and too little practical knowledge in much producer work.

2. We do not believe that faulty design and construction are nearly as much the cause of some failures as is the lack of knowledge of the particular equipment.

3. Many engine and producer builders are guilty. This also applies to successful designers of anthracite producers who attempt to build bituminous coal producers along impossible lines.

4. A majority of installations prove unsuccessful because of faulty design and construction.

5. After about a hundred of these installations had been made in this country by old firms that had the advantage of knowing practice in Europe, and when the business had begun to look very promising, there was a great influx of would-be builders without experience, who wasted millions of dollars, in addition to shipping more or less crude apparatus. Their responsibility ended when the bill of lading and the invoice had been made out. This crude haphazard method of doing business cast a great blight over the industry, and it took the public five or six years to find out that the majority of the goods being turned out were hopeless failures. It makes no difference whether the engine and producer were well built or whether they were not, so long as the installation is a failure. Part of the duty of every manufacturer in turning out goods is to see that they are properly installed and that the buyer is properly educated to use them in accordance with instructions given by the manufacturer. When the American manufacturer began to put his goods on the market he seemingly had no care as to the education of the buyer and was disposed to let him wrestle with this problem, in the same way that the agricultural implement manufacturer does to-day, regardless of the fact that there were no gas-engine experts in this country available in the remote places where these installations had to be erected. The same mistake is still being made.

PUBLIC UNCERTAINTY.

6. Lack of knowledge and confidence on the part of the public.

Judging from the statements of the manufacturers, this seemed in 1909 to be the greatest difficulty with which they had to contend.

The following comments show the opinions of manufacturers in 1912:

1. The producer is rapidly living down public uncertainty.

2. The public is not able to discriminate between correct design and faulty design. Arguments on this score are so full of sophisms that even an experienced engineer may be deceived.

3. The public have always been ready to buy, and if they had received good goods they would continue to purchase.

4. Some gas-engine builders have been loath to admit that under certain conditions the gas engine could not compare favorably with steam-power apparatus, and on this account there are many installations of gas engines in the United States in which the general conditions are quite prejudicial to good results. It was natural that such installations should create a prejudice against the internal-combustion engine, but this seems to be disappearing inasmuch as there is little difficulty at present in showing the advisability of a gas-power installation when it is warranted by the operating conditions.

5. Markedly decreased.

SEPARATE HEATING PLANTS.

7. The fact that the heating of factory buildings must be provided for by a heating plant separate from the power plant.

In 1909 the following statement was made by the author:

In the main this situation has not changed. Individual owners of producer-gas plants report that they are heating their buildings from these plants, but this application does not seem to be general. Until proper methods are devised for accomplishing this heating with entire satisfaction there will be many places in which, though producer-gas power plants would otherwise be desirable, it would be a mistake to make such an installation.

The manufacturers in 1912 expressed the following views:

1. Heaters are now designed that will do considerable heating with jacket water and exhaust. The advantage of a separate heating plant, as shown by actual installations and figures presenting cost of this arrangement combined with a producer plant, in comparison with cost of a steam plant, can easily be shown.

2. Heaters placed on the exhaust of the gas engine are now being used in not a few instances.

3. The writer has had a few cases come to his attention where a plant has not been installed because it was necessary to have boiler power for heating purposes.

4. The heating of buildings where power is generated by internal-combustion engines has of late been accorded considerable attention, and a satisfactory system has been developed in which the circulating water discharged from the engine is passed through a heater utilizing the sensible heat of the exhaust gases to further raise its temperature. From this heater the water may be piped to a hot-water heating system, thus realizing a marked economy, which, of course, should be credited in estimating power cost.

5. Gas-engine exhaust will raise jacket water to the boiling point. Little additional fuel is necessary to raise steam for heating. Successful exhaust heaters now

on the market are very simple. Steam-engine builders always use heating as an argument. Given a chance, gas-engine builders can furnish heat and power with very small reduction in comparative saving.

6. Inability to heat buildings is not a serious drawback. A great deal of heating can be done with the waste heat from a gas engine, and although there is room for much development in this line, the objection does not seem to be serious at present.

USE WITH BITUMINOUS COAL.

8. Lack of types of producers that will gasify bituminous coal satisfactorily.

Could the disinterested comments of a large number of producer-gas investigators be procured, the discussion regarding item 8 would, I believe, center about the word "satisfactorily."

The Government investigations at St. Louis, Mo., and Norfolk, Va., demonstrated without question that both the updraft, or pressure, producer and the down-draft type will generate an excellent gas from bituminous coals, entirely suitable for the commercial operation of gas engines.

There are, of course, inherent difficulties in each type, such as the mechanical extraction of the tar in the updraft producer, which reduces the efficiency of the plant and forces on the owner an undesirable by-product, and the excessive labor in cleaning the down-draft system, the requirements of cleaning also prohibiting the continuous operation of a single-generator unit. Undoubtedly modifications will be made that will reduce these objections to a minimum, and other developments will gradually simplify such plants; but even as the plants exist to-day the fact is that approximately 52 per cent of the total producer-gas horsepower in this country is developed from bituminous coal and lignite.

Owing to commercial considerations these installations for the most part use fuels of good quality—that is, the regular marketable grades. That it is not necessary to restrict the operation to these better grades, so far as making gas of the proper quality is concerned, was demonstrated beyond question by the Government tests.

The testing plant at St. Louis ran satisfactorily on many coals containing over 20 per cent ash. One West Virginia bony coal contained as much as 44 per cent ash, and with this fuel the consumption was only 1.65 pounds of coal as fired per brake horsepower per hour. Among the other fuels that may be classed as low grade and that were successfully used in this plant are large slaty roof slabs, or roof coal, Illinois bone, washery refuse, and Rhode Island graphitic anthracite.

Peat forms an excellent fuel.

With such a wide range of available fuels, and with the supply of anthracite and the better grades of bituminous coal decidedly limited, the producer types now in use will doubtless in due time be improved and modified so as to adapt them to the lower-grade or high-ash fuels.

The general situation in Europe is not very different from our own, as owners are for the most part using the better-grade fuels and leaving the poorer grades in the mines. They recognize this as a serious situation and are deeply interested in the possible utilization of low-grade fuels in the gas producer.

During an inspection trip in 10 European countries in 1908 I found anthracite coal, brown-coal briquets, and peat in general use in producer-gas power plants. Bituminous coal was also extensively used, but in most plants only noncaking coals, moderate in tar production and low in ash, were handled.

For one installation of many thousand horsepower the coal was taken directly from mines bought by the owners expressly for the use of their plant, but I learned that the high-grade, marketable coal was used in these producers and the grades relatively high in ash were not taken from the mines.

In two instances only was I able to learn of the use of high-ash fuels. In one installation a mixture of culm, roof coal, and washery refuse, reported as averaging 53 per cent ash, was being used in a by-product recovery plant. This plant, which was experimental, had been in commission about one year. Considerable time was required for adapting the plant for the successful handling of the fuel, but the reports indicated that for three months before my visit little or no difficulty had been experienced.

The other plant was at the time of my visit under full operation, using roof slabs that gave little indication, on casual inspection, of containing any combustible material. It was claimed that this fuel averaged over 60 per cent ash—a claim that seemed entirely reasonable. The producers were not only supplying a number of furnaces with gas, but were also operating a 1,000-horsepower and a 250-horsepower gas engine. A 500-horsepower engine was being added to the equipment. The engines in use were direct-connected to electric generators. The 10,000-volt current is used for operating the local mine machinery and also for furnishing lights for neighboring towns and power for a street railroad. The plant was reported to be using over 100 tons of this low-grade fuel per day.

In 1912 the manufacturers make the following statements:

1. The updraft producer for bituminous coal, using a centrifugal scrubber, has been generally successful. From our knowledge of the double-zone producers we believe that the question of the mains filling with lampblack and soot is a very serious problem, far greater than the mechanical disposal of tar.

2. There is a good demand for producers for small power to use bituminous coal. It is possible to manufacture a plant of this kind, but the first cost is so high as to be prohibitive in many cases.

3. Our experiments with bituminous coal have not been satisfactory. A satisfactory scrubber for the small plant is not available. Also in the small plant the labor for stoking is excessive when soft coal is used.

4. Bituminous producers, in large units, with proper auxiliaries, are successful. Small bituminous producers, owing to cost and difficulty of tar extraction, are not as yet successful.

5. Successful bituminous producers are now in operation, but not yet well advertised.

6. There is a lack of producer types for the use of bituminous coal. In fact there are altogether too many plants proposed for this service, all of which are tolerably successful. They are not, however, developed to a point where the confidence of the purchaser can be fully assured.

CHEAP FUELS IN SUCTION PRODUCERS.

9. Inability to use cheap fuels in the suction gas producer.

In 1909 the review of this situation was as follows:

One of the manufacturers has said, "A satisfactory suction soft-coal producer would be a great boon to the gas-engine and producer business." There are at present a few plants operating successfully on lignite, and in special cases bituminous coal has been used, but this practice can not be regarded as sufficiently satisfactory in all particulars to warrant the indiscriminate installation of such plants.

It is understood that the two producer plants now being erected in this country for operation with peat are of the suction type.

The suction plant is used in Europe for practically the same varieties of fuel as in this country, namely, anthracite coal, coke, brown-coal briquets, and peat. The number of such peat producer-gas plants is great.

My attention was drawn to only one suction plant in Europe actually operating under commercial conditions upon bituminous coal. This plant appeared to give entire satisfaction, but close inquiry brought out the fact that it was necessary to procure certain grades of coal and further that it was necessary to mix three varieties in definite proportions to insure successful operation.

There is certainly opportunity for further development along this line.

The views of manufacturers in 1912 are as follows:

1. There is no doubt but that suction plants require somewhat better grades of fuel than do pressure plants, although this difference has been overcome in a great many instances by the use of an exhauster. It almost always pays to use a good grade of fuel. "The better the leather the longer your shoes last."

2. Many cheap fuels can be used, but some are not suitable and should be avoided. Careful investigation along this line will always prevent trouble.

3. We do not consider the use of cheap slack coal in suction plants as at all necessary to the progress of the art. It would be very desirable, however, that the producer plant should be capable of using the same grade of fuel that is economical to use in the boiler plant. At present, however, this is not usually the cheap low-grade fuel.

RELATIVE FUEL VALUES.

10. Lack of complete knowledge as to how successfully the various fuels in different localities can be used in gas systems.

A special object of the investigations made at the Government fuel-testing plant for years has been to determine the relative fuel value of coals found in the United States, and it is expected that, as the results become available, this work will supply the necessary information concerning the various kinds of fuel tested.

The manufacturers in 1912 state:

1. This question should be investigated thoroughly by every producer manufacturer before installing a plant where there will be the slightest question of trouble from this source. Although chemical analysis will in a large measure supply the desired information, yet in some cases relative fuel values should be investigated to the extent of trying out the producer fuel proposed.

2. There is much to be accomplished in an experimental way in connection with various fuels. This subject has been gone into extensively by you in your investigations, but we believe that it would be well if a large plant could be installed, say of 500 to 1,000 horsepower, and operating particularly on these various fuels over fairly long periods of time, so that we would have a more exact knowledge of what they will do. It appears that there is a chance to gain considerable information of importance along this line from large plants already installed, but the writer does not know that anybody has looked into the matter in a systematic way and tabulated general information that might be obtained.

3. Information regarding the behavior of different fuels when used in connection with producer plants would prove of great value particularly as this information became more general.

4. Venturesome gas-producer builders and inexperienced salesmen are responsible for trouble from this source.

5. The required manner of handling one fuel as compared with another is seemingly well enough understood to prevent any serious difficulty from this score.

EXCESSIVE COST.

11. Large excess cost of gas-engine and gas-producer power plants over that of steam-power plants.

In 1909 my comment on the cost of producer-gas plants was:

After examination of many tables of costs, the conclusion is that complete producer-gas installations for the larger plants, say from 4,000 to 5,000 horsepower,[a] cost about the same as those of first-class steam plants of the same rating. With smaller installations the balance is probably in favor of the steam plant. However, even if the steam plant costs 15 per cent less than the producer-gas plant, it should not be forgotten that the increased efficiency in operating the latter will make up the difference in the first cost within a short time—probably in two or three years in the average plant.

It must be acknowledged that the cost of producer-gas power installations is excessive, and that there must necessarily be a reduction in price when the amount of business will warrant it. A most encouraging sign is manifested in item 10, page 12, in which a manufacturer actually says, "I do not believe that the high selling cost is warranted by the shop costs."

A transaction came to my attention in which a gas producer was offered at a figure which was reported to be "actual shop cost." Within 10 days another company offered a plant of the same rated capacity for one-third of the price, and this manufacturer casually remarked, "and I shall not lose on it at this price."

The demand for figures of the approximate cost of these installations has become so persistent that the following tables are presented, although somewhat incomplete.

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[a] A 5,500-horsepower producer-gas power plant complete, including electrical machinery, buildings, etc., all erected, is reported to have cost, including freight, $73 per horsepower. At the same time the report was published that the corresponding figures for a competing steam plant amounted to $74 per horsepower.

Cost of producer-gas engines, 1909.

Horse-power.	Cost f. o. b. factory.	Cost of engine erected, including foundation.	Cost per horsepower.	
			F. o. b. factory.	Erected, including foundation.
20	$1,100	$1,150	$55.00	
55		2,400		$43.70
60	2,800		46.70	
60	2,900		48.40	
75	3,610	3,933	48.10	52.40
80		3,300		41.20
80	3,400		42.50	
80	3,250		40.70	
80	3,830		47.90	
85	4,150		48.90	
85	3,550		41.80	
100	4,300		43.00	
100	4,925		49.25	
110	4,950		45.00	
110	4,960		45.10	
110	5,100		46.30	
112	4,200		37.50	
125	5,450		43.60	
130	5,250		40.40	
135	6,600		48.90	
150	6,200		41.30	
160	5,500		34.40	
160	6,100	6,770	38.10	42.30
185	7,800		42.20	
210	8,600		40.90	
250	6,650	7,360	26.60	29.40
300	10,500		35.00	
400	12,000		30.00	
400	12,800		32.00	
600	17,400		29.00	
1,000	33,750		33.75	
2,000	64,850	67,125	32.43	33.56

Cost per horsepower of producer-gas installations, 1909.

Horse-power.	Gas producer and engine erected, exclusive of foundations.	Gas producer and engine erected, including foundations.	Complete plant, exclusive of buildings.[a]	Complete plant, including buildings.[a]
20	$105.00	$108.50		
25	62.50			
25	115.00			
50	86.00			
60	69.50	74.50		
75	75.00			
75	86.50			
80	62.00			
100	67.00			
110	60.50	68.00		
110	62.50			
125	65.00			
125	90.00		$100.00	
150	70.00			
200	67.00			
250	65.00	68.00	79.00	$93.00
300	58.00			
500			84.40	
1,000	55.50		69.50	79.50
2,000	46.00	47.50	56.50	63.50
2,800				76.00
4,000				69.00
4,000				72.00
4,000				77.50
4,800				72.00
4,800				79.50
5,500				70.00

[a] Includes producer, engine, electric generator, piping, and auxiliaries, all erected, with suitable foundations.

Considerable variation will be noticed in the prices quoted by different manufacturers for plants of the same rated capacity. In some cases this difference is warranted by a difference in the "quality." In others it is due to a difference in the number of units installed to make up the total required horsepower or to different requirements for auxiliary equipment.

The following statements show the views of manufacturers in 1912:

1. The excessive cost will be reduced when increased demand cuts down the "overhead" expense of manufacture.
2. The excessive cost of plants, especially in the smaller sizes, seems to be a great drawback.
3. We believe that the cost of plants has been coming down in the past two or three years, but it is still rather high and future improvements will probably bring the figures down.
4. A good producer-gas power plant can be installed for just about the same money that would be required for a first-class condensing steam plant, and would show a material fuel economy over the latter. However, in the majority of small plants where producers would otherwise logically be used, the purchaser objects seriously to spending more money for a gas plant than would be required for an ordinary type of steam equipment. The large difference in fuel consumption does not seem to be important as compared with the additional investment required. We believe, however, that this handicap will soon be overcome.

In order that definite comparisons may be made between prices in 1909 and 1912 the following summaries of the data supplied by the manufacturers this year are added:

Cost of producer-gas engines, 1912.

Horse-power.	Cost f. o. b. factory.	Cost of engine erected, including foundation.	Cost per horsepower.	
			F. o. b. factory.	Erected, including foundations.
45	$1,950	$2,400	$43.30	$53.30
50	2,000	2,500	40.00	50.00
50	2,200	2,500	44.00	50.00
55	2,250	2,700	40.90	49.10
75	3,300	3,850	44.00	51.30
100	3,850	4,475	38.50	44.75
100	4,000	4,400	40.00	44.00
100	4,000	4,600	40.00	46.00
125	4,500	5,150	36.10	41.30
150	5,800	6,670	38.70	44.50
165	6,800	7,550	41.20	45.80
180	6,500	7,500	36.10	41.70
190	8,500	9,250	44.75	48.70
200	7,000	....	35.00	....
200	7,800	8,970	39.00	44.85
200	8,500	9,500	42.50	47.50
200	....	9,700	....	48.50
250	8,500	....	34.00	....
250	9,200	10,500	36.80	42.00
250	10,600	11,600	42.40	46.40
300	10,200	....	34.00	....
300	11,500	13,125	38.30	43.75
300	11,800	12,900	39.30	43.00
300	12,500	13,500	41.70	45.00
500	16,000	18,000	32.00	36.00
500	17,000	....	34.00	....
500	20,000	22,500	40.00	45.00
1,000	31,000	35,000	31.00	35.00
1,000	34,000	....	34.00	....
1,000	35,000	39,000	35.00	39.00
3,000	90,000	101,500	30.00	33.85

Cost of gas producers, 1912.

Horsepower.	Cost f. o. b. factory.	Cost erected, including foundation.	Cost per horsepower.	
			F. o. b. factory.	Erected, including foundation.
15	$396	....	$26.40	....
15	450	$500	30.00	$33.35
25	455	....	18.20	....
25	560	625	22.40	25.00
35	560	....	16.00	....
50	700	....	14.00	....
50	730	820	14.60	16.40
50	900	1,035	18.00	20.70
50	1,400	1,800	28.00	36.00
75	910	....	12.15	....
75	940	1,050	12.50	14.00
100	1,050	....	10.50	....
100	1,100	1,230	11.00	12.30
100	1,200	1,380	12.00	13.80
100	1,450	1,850	14.50	18.50
100	....	2,400	....	24.00
150	1,295	....	8.65	....
150	1,530	1,710	10.20	11.40
150	1,600	1,840	10.65	12.30
150	....	3,300	....	22.00
200	1,725	....	11.50	....
200	2,050	2,300	10.25	11.50
200	2,200	2,750	11.00	13.75
200	2,800	3,220	14.00	16.10
200	3,000	3,700	15.00	18.50
200	....	4,000	....	20.00
250	2,100	....	8.40	....
250	2,600	2,900	10.40	11.60
250	3,500	4,300	14.00	17.20
250	....	4,750	....	19.00
300	2,700	3,500	9.00	11.65
300	3,200	3,600	10.65	12.00
300	3,400	3,910	11.35	13.05
300	....	5,700	....	19.00
500	6,000	7,000	12.00	14.00
500	8,500	10,000	17.00	20.00
500	....	9,400	....	18.80
1,000	12,000	13,500	12.00	13.50
[a]1,000	14,500	17,000	14.50	17.00
1,000	....	18,700	....	18.70
[b]3,000	40,000	44,000	13.35	14.65

[a] 2 times 500.

[b] 5 times 600.

Cost of producer-gas installations, 1912.

Horsepower.	Cost of gas producer and engine erected, including foundations.	Cost of complete plant, exclusive of buildings.[a]	Cost of complete plant, including buildings.[a]	Cost per horsepower.		
				Gas producer and engine erected, including foundations.	Complete plant, exclusive of buildings.[a]	Complete plant, including buildings.[a]
50	$4,300	$5,300	....	$86.00	$106.00	....
100	6,250	7,800	$9,100	62.50	78.00	$91.00
200	12,400	15,800	17,500	62.00	79.00	87.50
200	13,200	16,200	....	66.00	81.00	....
250	14,800	18,200	....	58.20	72.80	....
300	17,000	22,000	23,800	56.65	73.35	79.35
500	25,000	29,500	....	50.00	59.00	....
500	32,500	47,500	....	65.00	95.00	....
1,000	48,500	57,500	....	48.50	57.50	....
1,000	56,000	84,000	....	56.00	84.00	....
3,000	145,500	202,000	....	48.50	67.35	....

[a] Includes producer, engine, electric generator, piping, switchboard, and auxiliaries, all erected with suitable foundations.

OVERRATING.

In 1909 the general statement in regard to overrating was:

> Among the difficulties in the way of the proper development of producer-gas power special attention is called to the overrating of producers. It is exceedingly gratifying to note that this point is at last recognized by at least one of the companies building these plants. This tendency to overrate producers has been especially prevalent among the builders of the suction plants. In inspecting a large number of installations throughout the country this weakness has repeatedly attracted attention. It has been observed frequently that a given plant using anthracite fuel of good quality will present no operating difficulties when working up to 50 or 75 per cent of the rated capacity of the producer, but if the producer is forced to its full rating for any length of time, clinkering and other operating difficulties are encountered. These are often sufficiently serious to necessitate a reduction in load at a time most unfortunate for the factory.
>
> This overrating has come about very naturally through early attempts to adopt European figures for rate of fuel consumption. Experience with American fuels has shown that decided modifications in this fuel-consumption rate are absolutely necessary, and although some manufacturers have given this matter careful consideration it is undoubtedly true that others are still using grate areas too small for the demands that their producers are expected to meet.
>
> In spite of the difficulties indicated, the producer-gas power plant is in the main an assured success. In fact, it is in the appreciation of these difficulties by conservative manufacturers that the possibilities of a steady and strong development lie. The true status of this type of power is well defined by a representative of one of the strongest companies in this country when he states that "the gas engine and producer have come to stay. They are of great economic value. They have their peculiar application, however, and are not a universal panacea for all our previous ills."

The replies received from manufacturers in 1912 state:

1. A frequent trouble which experienced builders will avoid in the future.

2. The tendency to overrate plants in the earlier stages of the producer business has been fully demonstrated. It is our belief, however, that the producer manufacturers are now supplying a great deal larger equipment for a given capacity than formerly. The fact that producers are rated in horsepower is in itself misleading. It is our belief that capacities should be designated by the internal diameter or area of the fuel bed. In other words, a comprehensive rating should be based on the number of heat units per square foot of grate surface.

3. We do not believe that there is so much of a tendency to overrate capacities of plants as there was formerly. In the infancy of the business, there was a tendency to claim extremely high efficiencies and a claim to gasify any and every type of fuel. This has been largely done away with; on large installations in particular special arrangements are made to take care of special conditions.

4. It might be well to mention one point frequently overlooked by gas-engine builders in the past, namely, the effect of altitude and high temperature on gas-engine capacities. Standard rating being made on the basis of sea-level atmospheric pressure and 70° air and gas temperatures, engines operating where these conditions seldom if ever prevail have been unable to give the desired results. To-day there is a more general appreciation of the physical factors affecting engine performances.

5. There is at present little tendency to overrate the capacity of plants, except possibly as applied to a given industry. It sometimes occurs that the maximum or peak load that may be reached in a given industry is underestimated, but the plants themselves are generally fully capable of developing their rated power.

6. The costs of plants have fallen rapidly and it is found better to overrate than underrate the plant. We have displaced producers with which the greatest fault has been underrating.

VIEWS OF OWNERS AND OPERATORS OF PRODUCER-GAS PLANTS.

NOTES OF INSPECTION.

Unfortunately no detailed examination of the plants in this country has been made by representatives of the Bureau of Mines during the past four years, but incidental reports, coupled with the fact that many owners have added to their installations during the past three years, lead to the conclusion that the general attitude of the owners and operators is at the present time even more favorable to producer gas than when the following notes were made. The information recorded below was procured through my personal inspection during the summer of 1906 and by C. D. Smith, an engineer of the Bureau of Mines, in 1908.

No plan was followed in selecting the plants to be visited, and, with one or two exceptions, no notice of the inspection was given the owners or operators before arrival at the plant.

In the following table are presented the essential details of the plants visited. The observations which follow the table were made and recorded at the time of the visits:

Summarized particulars of producer-gas power installations visited.

Plant No.	Producers.				Fuel.			Water supply.	Number of men required each shift.
	Type.	Number installed.	Total rated capacity, horsepower.	Internal diameter.	Kind and size.	Amount used (approximate).	Method of charging.		
				In.		*Pounds.*			
1	Suction..	1	25	......	Anth. pea.	1.25 per b. h. p. hr.	....	....	
2	...do.....	1	25	......	...do.......	....	3 times a day	City mains....	One.
3	...do.....	1	30	......	Anth. buck.	300 per day.	Once an hour.	....	5 hrs. time of one.
4	...do.....	1	30	......	Anth. pea.	....	....	....	Part time of one.
5	...do.....	1	35	......	Anth. and semi-anth., mixed.	1.6 per b.h.p. hr.	....	City mains....	One (12 hr. shifts).
6	...do.....	1	50	......	Anth. pea.	400 per day..	Varies with load.	Well..........	One 2 hrs. per day.
7	...do.....	1	50	28	...do.......	450-500 p. d..	Twice a day.	.....do.........	Do.
8	...do.....	1	50	......	...do.......	....	....	Pressure main.	
9	...do.....	1	50	......	...do.......	240 per day..	3 times a day	City mains....	Do.
10	...do.....	1	50	......	....	....	....	.....do.........	
11	...do.....	1	50	......	Anth. pea.	300-400 p. d..	3 times a day	.....do.........	Do.
12	...do.....	1	50	36	...do.......	700 per day..	.....do.......	Well..........	One.
13	...do.....	1	50	28	...do.......	1,340 per day	Every 30 mins.	Pressure main.	Part time of two.
14	...do.....	1	50	36	...do.......	450-500 per day.	Fill every morning, charge as needed.	City mains....	One 2 hrs. per day.
15	...do.....	1	50	......	...do.......	300 per day..	Twice a day.	Well..........	Do.
16	...do.....	1	50	30	...do.......	550 per day..	Every 25 to 30 mins.	City water....	Do.
17	...do.....	1	50	28	...do.......	650 per day..	4 times a day	Well..........	Half time of one.
18	...do.....	1	60	......	Charcoal..	1 per b. h. p. hr.	....	City main.....	One.

Summarized particulars of producer-gas power installations visited—Continued.

Plant No.	Producers.				Fuel.			Water supply.	Number of men required each shift.
	Type.	Number installed.	Total rated capacity, horsepower.	Internal diameter.	Kind and size.	Amount used (approximate).	Method of charging.		
				In.		*Pounds.*			
19	Suction.	1	60		Anth. pea.	335 per day.	Twice a day.		2 hrs. time of one.
20	do.	1	60		Anth. buck.	1-1.5 per b. h. p. hr.	3 times a day		Part time of two.
21	do.	1	60		Anth. pea.			Pressure main.	
22	do.	1	70		do.	300 in 7 hrs.		do.	One.
23	do.	1	75						
24	do.	1	75		Anth. pea.				Part time of one.
25	do.	1	80		do.				Two.
26	do.	1	95		do.	1,000.	6 times a day	Well.	Do.
27	do.	1	100		do.			City mains.	One.
28	do.	1	100		do.			do.	
29	do.	1	100		do.				
30	do.	1	100	36	do.	700 per day.	About once an hour.	Well.	Do.
31	do.	1	100		do.	1,000 - 1,200 per day.	3 or 4 times a day.	City water with cooling tower.	Do.
32	do.	1	120		do.	1,000 - 1,200 per day.	do.	City mains.	Do.
33	do.	1	120		do.	800-900 per day.	Twice a day.	Wells.	One 4 hrs. per day.
34	do.	1	125		do.	Less than 1 per b. h. p. hr.	5 times in 24 hrs.		One.
35	do.	1	125		do.				
36	do.	1	125		do.	850 per day.	3 or 4 times a day.	City mains.	Do.
37	do.	1	130		do.	875 per day.	4 times a day	River.	Do.
38	do.	2	(a)		do.				
39	do.	1	150		do.	1.8 per b.h.p. hr. inc. stand-by.	70 lbs. each hour.		Do.
40	do.	1	150	54	do.	500-600 per day.	Every 2 to 2½ hours.	Well.	Do.
41	do.	1	200		Anth. buck.	136 per hr.			
42	do.	1	200	84	Anth. pea.	1,000 per day	125 lbs. at a charge when needed.	City mains.	Do.
43	do.	2	200		do.	650 per day.	Every hour and a half.	Pressure main.	Two.
44	do.	1	200	60	do.	900 per day.	3 times a day	City mains.	One.
45	do.	1	200		do.	2 per b. h. p. hr.	1,000 lbs. charged each morning.		Part time of one.[b]
46	do.	1	300		do.	2,200 per day	According to need.	River.	Part time of three.
47	do.	2	300	42	do.	1,800 per day	Every 40 mins.	City water.	Two.
48	do.	2	350	54 66	Anth. buck., No. 1.	3,800 per day	Every 6 hrs.	Well.	Do.
49	Pressure.	1	85		Anth. pea.	800-1,000 per day.	175 lbs. at a charge when needed.	City mains.	Do.
50	do.	1	200		Anth. egg.	1,600 per day	4 times a day	Well.	Do.
51	do.	1	200		Anth. pea.	2,700 - 3,200 per day.	Every hour.	City mains.	Do.
52	do.	1	250	84	do.	1,700 - 1,800 per day.	150 lbs. about once an hour.	do.	Part time of two.
53	do.	1	250		Bit.				Full time of one and part time of one.
54	do.	1	250	84	Anth. pea.	3,000 per day	3 or 4 times a day.	Salt water from sea.	Part time of one.

[a] One 125 horsepower; one not stated.

[b] Plus general supervision.

Summarized particulars of producer-gas power installations visited—Continued.

Plant No.	Producers.				Fuel.			Water supply.	Number of men required each shift.
	Type.	Number installed.	Total rated capacity, horsepower.	Internal diameter.	Kind and size.	Amount used (approximate).	Method of charging.		
				In.		*Pounds.*			
55	Pressure.	1	300	......	Anth. pea.	1,000 per 540 kw. hrs.	....	....	Two.
56	...do.....	1	300	......	...do......	1,800 per day	Varies......	River.........	Do.
57	...do.....	2	400	84	...do......	1.33 per b. h. p. hr. or 7,000 per day.	Every 2 hrs.	....	Full time of two and part time of one.
58	...do.....	2	500	84	Bit. (New River).	5,300 per day (light load).	Every 20 to 30 mins.	Well; also city main.	Two.
59	...do.....	2	600	96	Anth. pea.	....	Varies; about once an hour.	River.........	Three.
60	...do.....	2	600	108	Anth. buck., No. 2.	10,000–11,000 per day.	About every hour.	.....do.......	Do.
61	...do.....	3	600	......	Anth. buck., No. 1.	5,000 per day	Every 2 hrs.	.....do.......	Two.
62	...do.....	3	750	96	Anth. pea.	....	According to need.	....	Three.
63	...do.....	3	750	96	Anth. buck., No. 1.	12,000 per day.	Continuous feed.	....	Do.
64	...do.....	1	1,750	......	Anth. pea.	....	....	....	
65	Downdraft.	1	1,000	......	Bit.......	....	....	....	
66	...do.....	2	1,000	......	...do......	15,000 per day.	Shovelful at a time.	Well.........	Five.
67	...do.....	1	1,500	......	...do......	1.4 per kw. hr.	....	Brook.........	Three.
68	...do.....	6	3,000	108	...do......	Varies much	Shovelful at a time.	Wells.........	Do.
69	...do.....	1	4,000	......	...do......	....	....	....	

Plant No.	Engines.					Hours operated daily.	Use of power.
	Type.	Number installed.	Rated capacity, horsepower.	Average load, horsepower.	Power transmission.		
1	1-cylinder, horizontal, 4-cycle, single-acting.	1	25	......	Belt drive to shaft.	([a])	Gristmill machinery.
2	.....do....................	1	27	([b])	.....do...........	([c])	Operating air compressors, stone surfacers, roughers, etc.
3	.....do....................	1	30	28	.....do...........	10	Machine shops.
4	.....do....................	1	27	26	.....do...........	10	Brick machinery.
5	.....do....................	1	35	([d])	Belt drive to generator.	24	Lighting restaurants, cafés, etc., running fans and ice-making machine. (Larger engine being installed.)
6	.....do....................	1	38	30	Belt drive to shaft.	10	Carriage shop.
7	.....do....................	1	50	40	.....do...........	10	Woodworking shop.
8	.....do....................	2	50	([e])	Gear drive to pumps.	8–12	Pumping station.
9	.....do....................	1	25	18	Belt drive to shaft.	10	Grinding and polishing.
10	.....do....................	1	38	......	.....do...........	......	Plant not running.
11	.....do....................	1	35	26	.....do...........	11–18	Coffee-roasting mill.
12	2-cylinder, tandem, single-acting, 4-cycle.	1	60	35	Belt drive to a. c. generator.	11	Machine shop and lights.
13	2-cylinder, vertical, single-acting, 4-cycle.	1	35	35	Belt drive to centrifugal pump.	24	Pumping station.

[a] Varying.
[b] Variable; over 30 horsepower at times.
[c] Usually 9; 12 at present.
[d] Variable; 1 to 24 kilowatts.
[e] 50 horsepower at times.

Summarized particulars of producer-gas power installations visited—Continued.

Plant No.	Engines.					Hours operated daily.	Use of power.
	Type.	Number installed.	Rated capacity, horsepower.	Average load, horsepower.	Power transmission.		
14	3-cylinder, vertical, single-acting, 4-cycle.	1	60	35	Belt drive to shaft.	12	Chocolate grinding and ice machine.
15	1-cylinder, horizontal, single-acting, 4-cycle.	1	20	10	do	10	Concrete mixer.
16	3-cylinder, vertical, single-acting, 4-cycle.	1	45		do	10	Wire-drawing machines.
17	1-cylinder, horizontal, single-acting, 4-cycle.	1	38		do	10	Factory.
18	2-cylinder, vertical, single-acting, 4-cycle.	1	[a] 68		do	10	Shoe machinery and a 100-light dynamo.
19	1-cylinder, horizontal, 4-cycle, single-acting.	1	25	20	do	10	Shop machinery.
20	2-cylinder, vertical, single-acting, 4-cycle.	1	50	30	do	10	225 sewing machines and a 12½-kw. dynamo for lights.
21	1-cylinder, horizontal, 4-cycle.	1	80	([b])	Belt drive		Town pumping and lighting station.
22	1-cylinder, horizontal, 4-cycle, single-acting.	1	65	20	Gear drive to pumps.	([c])	Pumping station.
23	3-cylinder, vertical, single-acting, 4-cycle.	1	75		Belt drive to shaft.		Machinery for grinding, polishing, etc.
24	1-cylinder, horizontal, 4-cycle, single-acting.	1	60			20	Shops.
25	3-cylinder, vertical, single-acting, 4-cycle.	1	70	([d])			Street and house lighting.
26	1-cylinder, horizontal, single-acting, 4-cycle.	2	80		Belt drive to shaft.	9	Foundry and shops.
27	3-cylinder, vertical, single-acting, 4-cycle.	1	55		Belt drive to 37.5-kw. generator.	24	Operating printing presses and lighting the block.
28	One 3-cylinder, vertical, single-acting, 4-cycle, and one 1-cylinder, horizontal, 4-cycle, single-acting.	2	100		Belt drive to shaft.		Machine shop.
29							Used only for testing gas engines.
30	2-cylinder, vertical, single-acting, 4-cycle.	1	100		Belt drive to shaft.	9½	Grinding and polishing.
31	3-cylinder, vertical, single, acting, 4-cycle.	1	100	60	Belt drive to generator.	10½	Machine shop and light.
32	1-cylinder, horizontal, single-acting, 4-cycle.	2	110		Belt drive to shaft.	9	Light and power for factory.
33	do	2	88	60	do	11	Gristmill and elevators.
34	3-cylinder, vertical, single-acting, 4-cycle.	1	75	90	Belt drive to shaft.	22½	Shops.
35	2-cylinder, vertical, single-acting, 4-cycle.	1	125			11	Grain-elevator machinery.
36	1-cylinder, horizontal, single acting, 4-cycle.	1	60	40	Belt drive to generator.	10	Light and power for shops; gas used for heating also.
37	do	2	120	60	do	11	Shops and factory.
38	2-cylinder, vertical, single-acting, 4-cycle.	1	150				Factory purposes.
39	3-cylinder, vertical, 4-cycle.	2	125	65	Direct connected to generators.	11	Electric power for factory and lighting.
40	3-cylinder, vertical, single-acting, 4-cycle.	1	89	45	do	10	Light and small machines.
41	1-cylinder, horizontal, 4-cycle, single-acting.	2	200		Belt drive to generator.	11	Factory purposes.
42	One 3-cylinder and one 2-cylinder vertical, single-acting, 4-cycle.	2	210	70	One belt drive; the other direct connected to generator.	10	Shops.
43	3-cylinder, vertical, single-acting, 4-cycle.	2	152	50	Gear drive to pumps.	9-10	Pumping station. (Duplicate plant.)
44	do	2	200	90	Direct connected to generator.	11	Machine shop.
45	do	1	100		Belt drive to generator.		Factory purposes.
46	2-cylinder, tandem, single-acting, 4-cycle.	1	200	160	Belt drive to generator.	11	Grinding and general purposes.

[a] By test.

[b] 15 horsepower for pumping; amount for lighting unknown.

[c] Varying; often 22.

[d] 60 horsepower at times.

Summarized particulars of producer-gas power installations visited—Continued.

Plant No.	Engines.					Hours operated daily.	Use of power.
	Type.	Number installed.	Rated capacity, horsepower.	Average load, horsepower.	Power transmission.		
47	3-cylinder, vertical, single-acting, 4-cycle.	3	300	100	Direct connected to generator.	14	Charging station garage.
48	.....do.....................	4	400	160	Two direct connected to generators; two metal-link belt drive to compressors.	24	Refrigeration, light, and power. (Duplicate plant.)
49	.....do.....................	1	85	......	Belt drive to shaft.	11	Light and power for factory.
50	1-cylinder, horizontal, single-acting, 4-cycle.	2	175	130	One, direct connected to generator; other, belt drive to generator.	10	Shops.
51	3-cylinder, vertical, single-acting, 4-cycle.	2	180	160	Direct connected to generator.	24	Generating current for electrolysis.
52	.....do.....................	(a)	(b)	60	.....do...........	11	Light and power in cleaning and dyeing plant. Gas also used for heating flatirons.
53	Horizontal, tandem, double-acting, 4-cycle.	1	250	250	.....do...........	11	
54	1-cylinder, horizontal, single-acting, 4-cycle.	2	250	......	One, direct connected to generator; other, belt drive to shaft.	10	Machine shop, cranes, and light.
55	3-cylinder, vertical, single-acting, 4-cycle.	3	415	(c)	Direct connected to a. c. generators.	[d] 24	Town lighting, both for streets and dwellings.
56	.....do.....................	1	270	150	Direct connected to generator.	11	Machine shop and foundry.
57	One 2-cylinder, vertical, single-acting; two horizontal, 2-cylinder, single-acting; five (in 1906—three in 1908) horizontal, 1-cylinder, single-acting, 4-cycle.	(e)	(f)	(g)	3 belted to generators; 3 belted to compressors; 2 belted to conveyor shafting.	(h)	Air and gas compressing-ash and coal conveyors, electric lighting.
58	2-cylinder, tandem, double-acting, 4-cycle.	1	500	475	Direct connected to generator.	12	Machine shop and lights
59	3-cylinder, vertical, single-acting, 4-cycle.	3	900	450	.....do...........	24	Shops and electric cranes.
60	2-cylinder, tandem, double-acting, 4-cycle.	1	470	390	.....do...........	10¼	Wire-mill machinery.
61	3-cylinder, vertical, single-acting, 4-cycle.	2	350	275	.....do...........	24	Machine shop and lights.
62	Two 3-cylinder, vertical, and one 2-cylinder, horizontal, single-acting, 4-cycle.	3	710	......	One, belt drive; two, direct connected to generator.	10	Shops.
63	1-cylinder, horizontal, double-acting, 2-cycle.	1	500	500	Direct connected to line shaft.	24	Paper-mill machinery.
64	.....do.....................	3	1,500	......	Direct connected to generators.	....	Street-railway service.
65	3-cylinder, vertical, single-acting, 4-cycle.	3	700	......	.....do...........	[i] 24	General manufacturing purposes.
66	.....do.....................	4	540	400	.....do...........	10	Machine shop and light.
67	Horizontal, single-acting, twin engines.	2	1,220	......	.....do...........	16	Street-railway service.
68	2-cylinder, tandem, double-acting, 4-cycle.	5	1,750	300	.....do...........	24	Central power station.
69	Vertical, single-acting......	5	800	800+	.....do...........	14	Shops.

[a] 1 in 1906; 2 in 1908.

[b] 90 in 1906; 210 in 1908.

[c] 20 to 90 kilowatts.

[d] 7 days per week.

[e] 8 in 1906; 6 in 1908.

[f] 460 in 1906; 400 in 1908.

[g] Night, 100 horsepower; day, 160 horsepower.

[h] One 21 hours, two 13 hours, three 18 hours, one 6 hours, one 14 to 20 hours.

[i] 6½ days per week.

PLANT 1.

1906.

Difficulties.—Plant absolutely worthless for intermittent service required by a grist-mill run on the basis that this is.

Remarks.—The owner of the mill believes that he was induced by misrepresentations to buy the plant. The agent claimed that it would be just the plant for varying demands; that it would fill the bill exactly.

He believes thoroughly in this type of power for continuous service or for 10 hours daily, but finds it worthless for his use. He fought payment a long time, but settled rather than have a lawsuit. He wants to get rid of the plant, and says that he has written the company many times trying to get them to take it off his hands.

He believes that the company has no men competent to install and operate plants. He said that the company might have installed a plant in the neighboring town if they could have started his without difficulty, but it took them so long to get his running properly that the other people would have nothing to do with it. He believes that the company is hurting itself seriously by its methods.

PLANT 2.

1906.

Difficulties.—Serious clinkering; producer well filled with clinkers after each day's run; large quantities of clinkers taken out every night; operator says that he sometimes gets coal that does not clinker badly. The plant fails to respond to the variable-load demands, so the operator has to help out with city gas.

Remarks.—The operator thinks the plant uses 30 horsepower when running full. This load comes on suddenly at times. He thinks the engine can do the work, but does not get gas enough from the producer. Somebody has told him that the producer is too small for the work demanded of it.

During my visit the operator kept jumping constantly from the air compressor to the city gas valve, admitting more or less gas to the engine as the occasion required. He also had to vary his air supply continually to secure proper mixture. He practically had to nurse the plant along at all times.

I noted that he knew nothing of the theory of the working of the plant, and further that he knew nothing of the construction or arrangement. The air inlet valves to the producer were both closed, so the engine could draw little air or steam through the producer. He did not know that he had any steam, and if he did have it did not know where it went or where it was supposed to go. He usually had to shut down at noon in order to blow his fires to obtain gas for the afternoon run. This blowing process required about an hour.

My impression was that the engine was actually running on city gas—was doing the work required and incidentally "dragging" the producer besides. I think the producer was furnishing very little if any carbon monoxide. The engine must have been pulling some air through the producer, probably through cracks around the doors and plugs, but it was not getting its air through the proper channel. I believe little or no steam was getting into the fires. The producer was too hot.

The indications were that the producer was well filled with clinkers at the time of my visit.

The previous month's city gas bill tends to verify the above conclusions, as it amounted to $60, according to the operator. He claimed that there had been months when the city's gas bill was only about $3.

The plant was installed either in December, 1905, or in January, 1906. The present man has been operating it seven months. He claims that the plant was put in with the understanding that it would cost only $1.50 to operate it, as the man who attended it could work on other things. He claims that at the present time it is costing per day $1.50 for coal, $2 for gas, and $2.50 for service. I believe that the prices for coal and service are somewhat overstated in this estimate. The engine had been running for three years and, he said, "without even having a screw-driver put to it." It seemed to be working fairly well, although with the erratic conditions that prevailed it was somewhat difficult to determine this point. The producer is charged with fuel three times every day—morning, noon, and night. The foreman of this plant seemed well satisfied with the uniformity in the running of the plant as far as he had noticed. The owner of the plant was not there.

PLANT 3.

1906.

Difficulties.—The operator said there were no difficulties. The plant ran very steadily during my visit. I understood there was some difficulty when the plant was first started, two years before, but the present operator, who had been with the plant about a year, claimed to have experienced no difficulty whatever.

Remarks.—The operator reported that he found considerable differences in the various loads of coal delivered to the plant, one load causing no trouble from clinkers and the next load giving considerable trouble. He regarded the producer as too small for the engine and the load carried. He felt that the producer should be large enough to require charging only every two hours without letting the bed get low. He asserted that there had been no shutdowns of the shop on account of the producer plant during his year of service. One of the office force whom I interviewed seemed perfectly satisfied with the operation of the plant.

PLANT 4.

1906.

Difficulties.—There was no difficulty at the time of visit, although there had been some from clinkers when the plant was first installed.

Remarks.—The plant has been running 10 months. The owner wanted a producer plant installed without any cost to himself until it had been run 30 days. He said that most of the companies wanted one-third on contract, one-third on shipping, and one-third when installed, without even proving the possibility of running successfully. He says that he finally found a company that would be glad to install the plant without a cent until after 30 days of successful running. He took up the offer at once, and the plant proved entirely satisfactory for 30 days.

About 10 days after the contract period—that is, 40 days from the time of installation—he had considerable trouble. He found that the operator sent by the producer company knew no better what the trouble was than his own man. Finally he found that the trouble was caused by a bridge of clinkers. After that experience the plant ran very satisfactorily. The owner is enthusiastic about the plant and would not do without it. He said that the plant cost him 35 cents per day of 10 hours, as against $2.80 per day with city gas.

PLANT 5.

1906.

Difficulties.—Trouble is said to be with the engine and generator rather than with the producer. The engine is undoubtedly too light for the load carried, and its construction is not suitable for producer-gas work, which accounts for the change of engines that was being made at the time of my visit. City gas is used in starting the engine and in case of emergency to help out the producer. With the new engine it is thought that the use of city gas will not be necessary.

Remarks.—If the present installation turns out as expected, the manager said he would increase the capacity as rapidly as possible. He wants to use bituminous coal if possible, and would like a producer for this purpose. The fuel used for this plant at the time of my visit consisted of one part Pennsylvania buckwheat anthracite and two parts semianthracite from Bernice, Pa.

The engineer said that he could regulate the height of the clinker bed at will with this combination of fuels. Another semianthracite coal which has been used to some extent is known as Spadra, Ark. When I visited the plant in the evening, a limited amount of city gas was being used to keep the engine up to full steady load.

PLANT 6.

1906.

Difficulties.—No difficulties if the plant is properly handled and supplied with proper coal.

Remarks.—The owner claims that the success of the plant depends entirely upon the method of handling the coal used. He says the producer company knows nothing about running this plant. His own company had to study the plant and had to run it. They got no help from the producer company. He further states that other plants of the same make have failed simply because of lack of ability and intelligence on the part of both the people using the plant and the producer people. He thinks he could make a great thing out of the producer business. He is exceedingly enthusiastic over his producer installation, but he does not feel that any of the credit is due the producer people. The credit belongs to himself and his company, who run the business and are interested in having things right.

The owner wants a specified anthracite No. 1 pea; can run on other coals, but has trouble with clinkers, and more work is required in operating.

The installation impressed me as excellent. The room was clean and well cared for.

I was told that the total water cost for this plant was equal to the coal cost.

1908.

The owner of this plant says his plant does fairly well, but that it is not all that it should be. He feels that he would have been better off had he waited until the present time before installing the plant. By so doing he would have had the advantage of the many improvements made during the past three years. With his plant there is too much that gets out of fix; first it is one thing, then another. Nevertheless he keeps the plant running and is satisfied that it furnishes cheaper power than any other he can get. He says that if he had not had a skillful operator the plant would have been down and out long ago. During the inspection the engine was running very steadily but with comparatively light load.

PLANT 7.

1906.

Difficulties.—Have to look out for tar in the valve stem. No trouble with producer at all; had a little trouble with the engine just at first.

Remarks.—The owner stated that 10 horsepower on gasoline cost $1.20 per day of 10 hours. He claimed that this plant, using only 40 to 50 horsepower, saves him $1,500 per year over any other type. He figures that it costs him a bit over $1 per day of 10 hours for 50 horsepower. He says his average cost is 80 to 90 cents per day.

The plant was put in in June, 1905. The owner says he would not take $10,000 for it if he could not get another like it. He thinks little of the ability of the man sent out by the producer company to install the plant. There were two or three men in the plant at the time of my visit who could operate it with perfect ease.

It was running very nicely during my visit and was not tampered with in any way. A 14-horsepower planer was suddenly thrown on. The engine slowed down a bit but picked the load up well. The engine is started by compressed air. City gas is connected for use in time of emergency, although they claim that it has not been turned on for months.

I was told that the installation of this plant has brought the insurance well down.

1908.

The owner of this plant is a thorough believer in producer-gas power. They have had considerable trouble and many annoyances from the plant installed, but the operating expenses are far below those for any other type of power. A year's cost record shows that during this time the profits from the sale of bale shavings were sufficient to pay for the coal, oil, waste, and all repairs on the gas engine. Had the steam plant been in use it would have consumed all the shavings made in the plant and in addition he believes as much coal as is used at present would also have been required. Further than this, a steam plant would require the services of a licensed engineer and a fireman.

Some difficulty has been experienced with the engine owing to the fact that it is not up to the specified rating. The conditions under which it operates are trying. It is belted to a 150-foot line shaft and various wood-working machines are thrown on and off at frequent intervals. The gas which the engine is getting is probably not very good, and further than this the engine is seriously overloaded. During this inspection it back-fired frequently, and whenever large machines were thrown on the speed was seriously reduced. The owner, however, is sufficiently satisfied to contemplate the installation of a larger plant.

PLANT 8.

1906.

Difficulties.—"All kinds;" plant not running. Runs at times, not at others. Clinkers badly, and the operator finds it impossible to get the blast of steam through the bed. The operator seems to think that with a clean producer (he was just cleaning out) and with new coal they could probably handle the plant without further trouble. Up to the present time (the plant has been installed eight months) it has done little.

The engine igniters have to be filed every day. They seem to be very soft, and look pounded as though the spring is too strong.

Six inlet valves have been broken during the eight months.

The engines are of the gasoline type, converted.

Remarks.—The operator says that he can start the plant in 20 or 30 minutes at times, but not at all at other times.

The operator seems to believe producer gas to be the coming power, but admits that he does not know how to handle it at present. He seems to think that the producer company does not know much more about it, as the man sent to erect the plant had difficulty in operating it. He says they did not seem to have competent men to put up and start the plant.

My own impression in this case and in that of plant 1 led me to believe that the manufacturers were not giving proper attention to their plants. As soon as they obtain the money they seem to let things run along without any further attention.

PLANT 9.

1906.

The proprietor seems perfectly satisfied with the plant and says that he would not exchange it for any other type of plant that he knows. This producer has been in operation one and one-half years, and in that time the fire has been out three times only. They find the plant easy to start every morning and also find that it requires little attention. They have at times had some trouble with the igniter circuit, but the owner considers this his own fault. They experience no trouble with blowholes and have never had any trouble with clinker; the ash, which is apparently free from carbon, looks about as fine as wood ash.

PLANT 10.

1908.

The gentleman interviewed was very strong in his denunciation of this plant. He stated that it had never run over a month at a time and that they had not been able to run it all for the last six months. He seemed to know no specific trouble save that they had broken three crank shafts on the engine, but his feeling is that the whole plant is no good. He stated that others of the company who were not present could give a long list of troubles. He also stated that the producer people have themselves started the plant several times, but after running a few days it would cease operations entirely.

Inquiry from outside parties who own similar plants with which they are well pleased gave the impression that the whole trouble is lack of intelligent operation and care.

PLANT 11.

1908.

Difficulties.—There were difficulties only when the plant was first installed, due entirely to lack of knowledge on the part of the owner and operator.

Remarks.—One of the proprietors stated that he would not ask for a more reliable or more economical plant. Before this installation the factory was run by means of gas engines using city gas. The gas bill averaged $800 per year. With the present installation the fuel cost for the first year has been approximately $200.

The engine is provided with two igniters. During the operation of the plant this precaution in providing an extra igniter has prevented shutdowns on three different occasions.

The ash contains considerable unburned fuel. The grate is cleaned every morning. It is stated that it is during this cleaning that the coal is taken out with the ash. When they have time this coal is sifted out of the ashes, but during much of the time no attempt is made to save this fuel.

PLANT 12.

1908.

Difficulties.—The chief engineer stated that although they had numerous minor difficulties at the start they got along very well and at the present time are getting very satisfactory service.

Remarks.—The plant has been in operation one and one-half years. The business manager of the firm says he is thoroughly satisfied with the installation, but stated that he did come into contact with the details of operation. The points which come to his attention are the cost of fuel and repairs and the failures of the plant to run. In these particulars he says the plant is all right.

Apparently about 20 per cent of the fuel charged into the producer appears in the ash, but as the plant is using only approximately 700 pounds of coal per day, they find it hardly worth while to attempt to save the good fuel that passes out with the ash. The fire is thoroughly cleaned each morning. It is during this cleaning process that most of the coal passes through the producer. The fire has not been drawn for three months. On the average three-quarters of an hour is required each morning to put the producer in working condition and get the engine under way.

PLANT 13.

1908.

This plant was not in operation at the time of inspection. The cause for the shutdown was given as a broken belt. A steam pump was doing the work at this time. New settling basins have just been installed which are much higher than the old. This increased head is said to be too much for the gas-engine plant, so that the gas engine has been unable to handle all the work and it has been necessary to help out with steam pumps. There has been some talk of installing a larger producer-gas plant in order to handle the entire output.

Ashes are removed from the producer about every two hours, and owing to the demands on the plant the engine slows down considerably at such times, but picks up immediately. By this method of operating continuous service can be maintained, although the power developed by the plant varies considerably, owing to the periods when the speed of the engine falls off. The engine is usually run continuously for six days, but at times it is kept in service for two weeks. The kind of service that proves satisfactory for a pumping station might be quite unsatisfactory in other types of installations.

PLANT 14.

1908.

This plant is operated by an enthusiastic young man who apparently understands the principles of his plant thoroughly and is getting excellent results. He says there is nothing like a gas-producer plant for him. When he first began operating he had some clinkers, but by varying the quantity of water admitted to the vaporizer he finally found a point where no clinker seemed to be formed. Since this time he has been able to keep his plant practically free from clinkers. He experiences no difficulty when removing the ash from the producer with a normal load on the engine.

PLANT 15.

1908.

This plant has been in operation about one year and has given little trouble. It was not in operation at the time of this inspection, as the engine has just been sent to the factory to have the cylinder rebored. The representative of the company interviewed thinks that the engine has been allowed to run for some time with little or no jacket water, owing to carelessness of the operator. He stated that he considers the outfit all right, and that he would not hesitate to put in a producer plant for any power requirement.

PLANT 16.

1908.

This plant has been in operation for five years. Both members of the firm say they could have nothing better or more reliable. During the first year they had considerable trouble and the manufacturer did not seem able to help them out to any extent. The producer company threw the blame on the engine company and the engine company blamed the producer company. Finally the owners agreed to disregard the suggestions and advice of the manufacturers entirely, and started in to work out for themselves proper methods of operating. After numerous experiences they determined on methods that have been giving satisfactory results. They feel that they are still gaining information and are developing more confidence in the reliability of such installations. In building a new fire they find it quite simple to have the load on the engine within 40 minutes after lighting the match. The firm has recently enlarged its shop and expects to put in a larger power plant. They say that they will not for an instant consider any other than producer-gas power.

PLANT 17.

1906.

One of the members of the company stated that they are learning the methods of handling this plant so that they now like it very well. For the first year or so it gave a great deal of trouble, but this they attribute to their lack of operating knowledge. The plant has been in three years and for the past year and a half has been run by an ordinary laborer. During the first year there was considerable trouble in clinker, but of late there has been no such difficulty.

PLANT 18.

1906.

Difficulties.—The engineer said there were no difficulties at present, but stated that as this was an early type of producer he found it necessary to make several minor changes in the steam-supply pipe, etc., to secure good operation.

Remarks.—Minor fluctuations in the speed of the engine were noted. The engineer claimed that this occurred only when the engine was under heavy load. My impression at the time was that these fluctuations were due to variations in the quality of the gas. They were not, however, serious or frequent.

Electric lights were thrown on and off without apparent fluctuations of the engine. The light was fair in quality and steadiness.

PLANT 19.

1906.

No difficulties are had with this plant. It had been running since February, 1906, and had never been shut down on account of any failure in the operation of the plant. They had been troubled with clinkers only once. The owner advises the thorough cleaning out of the generator every three months. He said that without counting the cost of water in either case steam power costs him $100 per month, while the cost of operating the present plant is less than $25 per month. He had not paid a cent for repairs.

The large producer plant was bought in order to have sufficient power for a second engine, if desired later.

The owner stated that he had operated many steam plants and knows steam thoroughly. He is exceedingly enthusiastic regarding the operation of his producer plant. He said that every manufacturing establishment in the vicinity has watched the producer installation very closely, believing it to be a foolish venture, but now others are thinking of making similar installations. The men in the shop are constantly being asked by outsiders if they haven't had to shut down yet.

There was no apparent noise of the exhaust in approaching the plant. An exhaust pit is used. There was no more noise than with the ordinary steam plant of the same size and nothing visible, such as smoke, steam, or chimneys. Upon approaching the plant I was very much in doubt whether the producer was running. The installation is very neat. The plant was not touched during my visit and was running well.

PLANT 20.

1906.

The plant had been operating one year without any difficulties. The engineer stated that during the year they have been shut down only three hours, the one time being due to a water leak in the engine cylinder head.

The engineer has entire charge of all machinery, etc., including the sewing machines. He employs a boy, who attends to the packing and shipping of the goods, to feed the fuel into the producer and poke the fire occasionally. They intend to enlarge the plant to 150 horsepower.

PLANT 21.

1906.

The plant was not running when visited. It is a new plant, erected in the spring of 1906, and presented an excellent appearance. The engineer stated that the company that installed the plant never instructed any man definitely about running it. He finds himself able to run it at times, but not at others. He never knows whether he is to get gas of good quality or not. After it is once started he says it runs well, but, as he puts it, the fact is that he knows nothing about running it and has never been shown. He seemed to be an able, intelligent man and desired instructions.

The man who erected the plant is reported to have gone around the corner of the building every time he consulted his blueprints for fear the engineer and others would see them and gain some knowledge of the construction of the plant. At other times the blueprints were kept locked up. I was informed that an operator of a similar plant in another part of the country was sent to this plant later and operated it with no difficulty.

Compressed air was used for starting the producer-gas engine. This air was pumped by a gasoline engine, which at that time was pumping water, but in regular operation the air is compressed during the run and kept in reserve.

The blast for starting the producer was furnished by a small blower, driven by a small gasoline engine installed for the purpose.

PLANT 22.

1906.

The operator says there are no difficulties. He likes the plant and is anxious to get all the information possible in order to equip himself for the proper handling of such plants. I was much pleased with his appearance, ability, and enthusiasm.

The fuel used, anthracite No. 1 pea, looked dull and poor, but seemed to work well. There was also a pile of bright anthracite. The operator said that the mixture of these two coals caused serious clinkering. He also asserted that the reuse of partly burned coal from the generator produces clinkers.

PLANT 23.

1906.

The engine was reported as worthless. The plant was installed in January, 1906, and ran about half of the time for four months; then the engine broke down and has not run since. At the time of my visit the power was furnished by a steam engine. They may possibly get back to gas if they can find a good gas engine.

The engine was not designed for producer-gas work. In fact, its only merit, in my opinion, was its low cost. The use of such engines is a serious setback to the success of producer installations.

PLANT 24.

1906.

In recent installations for a guaranteed service of 24 hours per day this producer company is putting in two gas generators, as they find it necessary to draw the fires from one generator each Sunday; that is, once a week.

PLANT 25.

1906.

The plant had not been in operation for several weeks. Several men from the producer company had just overhauled the plant. It had been in only a short time, but the producer was being relined. New bearings were being put in for the engine crank shaft, etc. One of the men remarked that the plant was in terrible shape and laid the blame on the man who had had charge of it. Inquiry regarding the operation of the plant indicated that he was incompetent, having left the plant to a helper who knew little or nothing of its requirements.

PLANT 26.

1908.

Difficulties.—Considerable trouble is experienced in this plant from clinkering of the fuel. This has caused several shutdowns, although at times they are able to run for several weeks without any inconvenience.

Remarks.—This plant had shut itself down just before inspection. Upon examination the producer was found to be badly filled with clinker. Apparently the cleaning had not been properly done for several days. The works are entirely dependent upon the producer plant for power and any interruption in the service means considerable expense. At one time the plant was out of commission for three days. At another time the engine stopped during a heat in a cupola, cutting off the blast. The entire charge was dropped and the day lost. The superintendent says their experience leads them to feel very uncertain regarding their power. Apparently the greatest trouble at this plant is a lack of operating knowledge.

PLANT 27.

1906.

The producer operator whom I saw likes the producer, as he can sleep and let it run itself and can go out of doors when he pleases. He had just smashed two holes in the engine cylinder head, so that the plant was shut down for repairs. He said it would run from one hundred and twenty to one hundred and twenty-five hours without shutting down, and then required about six hours for cleaning, etc.

The producer had been installed about two years; the present engine about four months. The plant was provided with a patented process, which had been in operation only four weeks. The producer operator liked this new process because he could sleep for six hours without charging the producer, whereas with the ordinary method he had to charge every two hours.

PLANT 28.

1906.

Difficulties.—All kinds of difficulty were experienced at first; changes have been made ever since the plant was installed; a new 2 or 2¼ inch top plate was put on in place of the ⅜-inch plate used by the manufacturers. The superintendent said the vaporizer never made steam, so he introduced a steam pipe from the boilers to help out.

The plant was shut down at the time of my visit on account of clinkers. The operators must have taken out 2 bushels of clinkers in large masses. The superintendent said that they had had no such trouble in three months, as his former operator handled the plant well, but they had to dismiss him. It seemed that during the last days of the service of the former operator the plant was not properly cleaned and the clinkers began to accumulate.

Remarks.—The superintendent said that the gas-producer company showed no interest in the plant whatever; he would not have the plant if it were out, but as long as he has already put it in, he is making the best of it. He is changing it in every way possible and claims that it has been running well for three months. The former operator was paid $1.65 per day.

The superintendent believes in producer-gas plants, but not in the one installed by this company. I was unable to learn of any other installation of this make of producer.

PLANT 29.

1906.

This plant had been running about nine months. The plant is reported to work splendidly since special charging equipment was added, although before this addition some back firing and preignition were experienced.

According to the superintendent the company is greatly pleased with the results of the plant at present. Before the addition of the special equipment the compression carried by the engine was 120 pounds. At present they are carrying about 200 pounds.

1908.

This plant was not installed for continuous operation. It is used only for the purpose of testing engines manufactured for operation on producer gas. Its service in this capacity has given satisfaction.

PLANT 30.

1908.

The owner of this plant states that they had many minor difficulties to overcome at the start, but these he feels were due to ignorance on his part more than anything else. At present he is very well satisfied with the service and regards the power as the cheapest he can possibly obtain.

PLANT 31.

1908.

This plant has been in three years. According to one of the members of the firm it has given all kinds of trouble. He found it impossible to get an experienced man to handle it. He finally taught an Italian laborer to do the work, and for nearly two years he has handled the plant. They are getting much better satisfaction from it now than ever before, but they feel much in doubt regarding the reliability of the engine. Apparently the engine has not been kept in good condition. The crank shaft needed lining up and the crank-pin bearings were apparently loose. The shutting-down hour came during the inspection, and it was noticed that the Italian operator thought more about getting away in a hurry than about putting his plant in proper condition. The company has an electric wire run in from an outside source which can furnish current whenever the gas fails.

PLANT 32.

1908.

The superintendent is very well satisfied with the plant. It has been in operation over three years, and during that time it has not been shut down three hours because of any fault of the engine or producer. The operator is an exceptionally good man and one in whom the superintendent has confidence.

The producer is cleaned thoroughly every Friday night and a new fire is built up at once, so that it is in readiness Saturday morning. The operator says that the producer would run much longer without cleaning, but by this systematic method of handling the plant he keeps his producer in good condition at all times, and no clinker can accumulate for any length of time even if some should form.

The operator considers the stand-by losses as practically nothing, but they are probably somewhat greater than he estimates. The operator allows himself one-half hour each morning for putting the producer into condition and getting the engine under way. He finds that it takes no longer to start the plant on Monday morning than on any other morning during the week.

PLANT 39.

1906.

The plant seemed to run fairly well. According to the statement of the owner, there was some trouble at first. They have some trouble with the magneto, the spark being cut out at times. This happened while I was present, when they shut down the plant.

They have some trouble with poor gas occasionally. Some weeks there are no shutdowns, while at other times there will be two or three in one week. These are, however, of short duration.

Occasionally they have been troubled with clinkers.

PLANT 40.

1906.

A member of the firm reported that the plant had been in operation fifteen months, during which time it had never failed. He said that it used very little coal, and he considers it the cheapest kind of power. At the time of inspection the factory was shut down for two weeks, and the plant was consequently not running.

The operator seemed to be exceptionally well informed regarding producer gas. The plant, like many others, has a producer of large capacity operating on a low-load factor. The demands in this case amount to only about 30 per cent of the capacity of the plant. After talking with the operator I was convinced of his ability to handle the plant with ease, and it is not difficult to see why the members of the firm feel great confidence in their power plant.

PLANT 41.

1906.

Difficulties.—There were troubles at first; the producer was too small; they had to get a larger producer; the valve cams on the engine were wrong; the manufacturers would not show them anything.

The producer company claimed that all the troubles were due to the fact that a steam engineer was in charge of the plant. The owner was satisfied that this was not the case, so he got a larger producer, reground the cams, had the valves reset, and now has the plant running in excellent condition.

Remarks.—This plant was installed in January, 1906. A long time was spent looking into the matter. Minneapolis, Chicago, Philadelphia, etc., were visited in order to judge of various plants. The engine was what decided the choice. The manager does not like vertical engines, as he wants an engine so constructed that one's hands can be put on any part of it.

Some difficulty was experienced with magnetos.

They have had some trouble caused by the stripping of the thread of the engine-valve stems. This happened while I was present.

They are running the exhaust into the fire box of a vertical boiler to heat water and also to do away with the exhaust noise.

The engine was belted to a 150-kilowatt electric generator.

They handle the clinkers in the producer rather successfully with bent pokers. They have had to put extra holes in the producer for this purpose.

The plant is very neat and apparently is well understood.

PLANT 42.

1906.

The president of this company stated that he did not wish to be too enthusiastic about producer-gas power, as there are many minor difficulties to be overcome. He feels that his plant is fairly satisfactory and thinks he can make it absolutely satisfactory in due time. He said that were he to build another factory he would not hesitate to install a producer-gas outfit for developing necessary power.

PLANT 43.

1906.

This plant is used in connection with pumping stations. The water is pumped a distance of about 12 miles, and it is proposed to extend the line some distance farther. As the water supply is unlimited, no effort is made to economize in the use of water about the plant.

The operator stated that he has some difficulty in procuring a satisfactory lubricant for the engine crank case.

The operator feels that care is necessary in getting a proper kind of coal, as trouble has been experienced with certain coals on account of excessive clinkering. Ordinarily the fire is drawn and the producer thoroughly cleaned once a week, but at present this is being done twice a week. The operator feels that it is very important to keep the producer clean and free from clinker. He regards it as no hardship to dump the fire and start a new one. He says that he can get the producer in shape for his usual load in one hour after lighting the match. He believes thoroughly in gas producers, but says they will not take care of themselves, as some manufacturers try to make out.

PLANT 44.

1906.

This plant has been in operation nearly two years. The fire has been out but twice. It was drawn once to put in a new grate and at another time to examine the brick lining. The superintendent seems very well satisfied with the installation and feels that his plant is doing as well as any. He seemed careful not to mention anything against the system, but his casual remarks would lead one to believe that he thinks improvements might be made.

They claimed to have no trouble from clinker. The ash pile was comparatively free and clear, the few clinkers in the pile not being larger than the fist. There was, however, considerable unburned coal. This was said to be due to the cleaning which the producer received every morning.

PLANT 45.

1906.

Difficulties.—There is a good deal of trouble from back firing. At the time of my visit the electric generator was sparking seriously and burned out before I left the plant.

Remarks.—On the whole, the company seemed to be fairly well pleased with the results. The method of handling the producer was wasteful of fuel, as about one-third of the coal charged to the producer was taken out unburned in the ash. This mixture of ashes and coal was used on the walks about the plant.

PLANT 46.

1908.

The representative of the company consulted stated that the plant had been in about two years, and that although they have had numerous difficulties these are being gradually overcome and at the present time the plant is giving fair satisfaction. The producer has never given any real trouble except that due to clinker formation, when a bad coal is used. The engine is the first of its kind and naturally gave a good deal of trouble. The engine builders, however, made numerous changes and it is now working much more satifactorily. He feels that in spite of the difficulties the gas-engine and gas-producer installation is the most economical power plant, and that in time all troubles will be overcome.

PLANT 47.

1908.

This plant is running very satisfactorily at present. The engineer in charge feels that he now has the plant well in hand. He has confidence in it as a source of power. In the early days of the plant they had considerable trouble, but he feels that this is due to a lack of operating knowledge more than to anything else. The engineer in charge stated that he was a steam engineer and that he preferred steam, but that the economy possible with gas makes it necessary to learn to use it.

PLANT 48.

1908.

This plant has been in operation only six months and is one of the few plants with which no trouble has been experienced during the early operating period. The engineer in charge says that he had never had any experience with producers or gas engines until about a year ago. Although a steam engineer, he sees a great future for the gas plant and says it is useless to be prejudiced. He takes much pride in this gas plant. He is also in charge of three or four steam plants for the same company. The gas-plant installation is in duplicate throughout. Usually but one producer and two engines are in operation at any given time. Each engine has a city gas connection, but it is stated that this is seldom used and was put in simply as a precautionary measure. Part of the engines are run at a constant overload of 20 per cent. They seem to carry this without difficulty, and upon one occasion one of the engines carried this overload continuously for 168 hours. Usually the change of units is made more frequently. At the time of this inspection the engines were running very smoothly and with little noise. It was impossible during the casual inspection to detect any variations in speed.

PLANT 49.

1908.

Difficulties.—There were numerous difficulties when the plant was first started, due to clinkers, back firing, poor ignition, etc., but at the present time there is practically no trouble.

Remarks.—The manager feels that the plant is giving very good satisfaction considering the fact that producer-gas plants are so new. The two young men who handle the plant have, I believe, had no experience before taking this job, but they seem to be getting hold of the method of operating very satisfactorily.

PLANT 50.

1908.

The gas producer originally installed was a suction plant, but it has been cut up, patched up, and changed over in many details until it is now running as a pressure plant. The member of the firm consulted is much disgusted with producers and producer manufacturers. He apparently has his own ideas regarding the construction and operation of producer plants, which accounts for the many changes which have been made in the present installation.

PLANT 51.

1908.

This plant was installed a little less than a year ago. It is giving continuous service (24 hours per day) in a satisfactory manner. A short time before this inspection carelessness on the part of a stoker disturbed some of the fire brick in the producer lining, making it necessary to draw the fire in order to make the repairs. Previous to this mishap the plant had been operating continuously over four months. Each Wednesday the load is reduced one-half, and during that time one engine can handle the load. In this way each engine has a day of rest once in two weeks. The igniters are changed and every part carefully examined. The superintendent of the plant is well satisfied with the operation.

PLANT 52.

1906.

Difficulties.—There are no difficulties now; those they did have, the owner stated, were due to careless operating rather than to inherent faults in the plant.

Remarks.—This plant has been in operation two and one-half years. Besides the gas used for power this plant also furnishes the gas for heating 150 irons in the ironing and pressing room. The heat is found to be steady and very satisfactory. They formerly used city gas, but find the present arrangement far more economical. They still have the city gas connections for the irons in the same pipe system, but have no occasion to use it.

They purify the circulating water and use it in another portion of the work.

I was told that cheaper fuel is used in the producer than under the steam boilers.

At present they are laying the foundation for the installation of another engine in addition to the present one.

The owner stated that although he regards the initial cost of such a plant as higher than the cost of a corresponding boiler plant, there is, in his opinion, economy in additions to the plant; that is, producers can be added without adding extra scrubbers, holders, etc., and thus have a reserve plant for less cost than a reserve boiler plant.

No odor of gas was perceptible in the ironing room. This gas is supplied by pumping; a rotary blower is used for the purpose; the pressure is low. The gas burned with a steady blue flame.

1908.

Difficulties.—There is no difficulty whatever when the coal desired can be obtained. When any coal that happens to be delivered must be taken, difficulty with clinkers is frequently experienced.

Remarks.—The owner is very well satisfied with the plant, although numerous difficulties due to lack of knowledge arose during the early period of operation, and the repair expense at this time was considerable. His statement regarding fuel cost is to the effect that 1,700 pounds of coal used in the gas producer does the same work which was formerly done by city gas costing over $40.

PLANT 53.

1906.

There were slight difficulties at first with mixtures, etc., but none now. The plant is very satisfactory. It has been running over a year. The engine is directly connected to a 150-kilowatt electric generator.

They claim to have had no trouble from the action of sulphur. I noted occasional back firing in one end of the cylinder.

The exhaust is used for heating feed water for the steam plant. The gas engine is run in parallel with the steam engine.

There is no exhaust noise; they use large exhaust ports of special form, making the pipe connection "flaring" in such a manner as to accommodate the expansion of the gas.

The producer operator receives 20 cents per hour.

PLANT 54.

1906.

The representatives seen feel that their plant is giving satisfaction and requires but little attention. They feel as much confidence in the reliability of the plant as they would in the steam plant. It should be stated, however, that the representatives are interested in the manufacture of this type of plant.

PLANT 55.

1906.

All kinds of difficulty were experienced with the old type of producer, which is now being torn down; no difficulty with the new type now in operation. This new producer is liked very much by the engineer. A second producer is to be erected at once.

There is no gas holder; automatic steam control is used. The engineer said it worked well. Steam pressure of 50 to 80 pounds is carried in auxiliary boiler.

The fires had not been drawn since the new plant was put in operation five months before. The engineer thinks the difficulties in most cases are due to the operator and methods used rather than to the plants themselves. He believes in the plant thoroughly; is interested and wants to learn.

The engine exhaust is run into a pit filled with broken rock; the noise is hardly noticeable.

PLANT 56.

1906.

Difficulties.—The plant has been installed about nine months. During the first two months, according to the owner, they had all kinds of trouble; clinkers as big as a barrel, poor gas, large coal consumption, back fires, etc., but these troubles seem to be past, as they have been overcome by experience.

Remarks.—The owner feels that producer manufacturers do not give sufficient and proper instruction when installing a plant. They leave too much for the purchaser to learn from his own experience. He says that at the present time he is undoubtedly using less coal than he would with an equivalent steam plant, but he is inclined to believe that this saving is offset by extra oil and labor which his gas plant requires. Before his purchase the producer representative made a strong point of the adaptability of the producer to cheap and low-grade fuels, but now that he has the plant in he finds that they are able to use only the best grades of coal.

The engineer in charge of the plant seems very well satisfied with the results they are obtaining and considers it an excellent installation. He says that all the trouble at the beginning was due entirely to lack of knowledge on the part of the operator and to an attempt to do many things which were not practicable. Another disadvantage at the start was the fact that the man employed on the producer was a cheap laborer with no knowledge of producer practice. These difficulties have been overcome, and the engineer says that he would not ask for a better plant than this has proved to be for several months past. The engine operator is regarded as a man of more than average ability and it is seldom that anything wrong develops in the engine room. The engineer stated that when the producer was in proper shape they never knew the engine to fail. He also stated that as a rule he could carry the load within two minutes after starting the engine.

PLANT 57.

1906.

There were no difficulties with the producer and none with the engine were mentioned, although the opinion seemed to be that some of the engines were not adapted to the work demanded of them.

At the time of my visit these producers had been installed nearly seven and one-half years. From one the fires were not drawn for six years and ten months. The fire was drawn then in order to put a new top on the producer. The lining of the producer was found in perfect condition, and not a brick was renewed. It had been five years since the fire was drawn in the second producer, and the engineer stated that he did not know when it would be drawn, as there was no reason for doing it.

The economizer tubes fill after a time, so it has been customary to change these about every two years. The old tubes are cleaned and replaced two years later.

Engine (*a*) had been installed two years, and had given entire satisfaction. It was running well when I visited the plant.

The two engines (*b*) had been in over seven years. They were installed with the original plant. The engineer objects to the hit-or-miss governor on the engines.

Of engines (*c*), two had been in six years and one five years. These were running satisfactorily while I was there.

Engines (*d*) and (*e*) are about 1,800 feet from the producer plant. Engine (*d*) seemed to be helped out occasionally by city gas—"only occasionally," I was given to understand, but engine (*e*) was run almost entirely by city gas.

The engineer was greatly pleased with the producer plant. He said that he experienced no difficulty with the producers and that they gave excellent satisfaction. One producer was operated with automatic feed, but the other was not.

1908.

This plant has been in operation since April, 1899. In one of the producers the fire has not been drawn for over seven years and is in good working condition at the present time. The other producer gave continuous service for six years and ten months from the time of installation. At that time the producer was in good working shape, and according to the statement of the engineer could have continued in service but for the fact that a distributing plate in the automatic feed fell into the producer. This caused such damage that it was necessary to draw the fire. After necessary repair the fire was rebuilt and has not been drawn since.

The ashes are removed from each producer every other day, during the period of lightest load, when it is possible for one producer to carry the load. The ash pile was practically free from carbon and clinker. The engineer stated that he accepts any pea coal for the producer that does not contain an excessive amount of dirt and fine stuff. The engineer in charge of the plant has been with it about seven years. He is an enthusiastic gas-power man and believes that the cause of most producer failures is the lack of competent operators.

PLANT 58.

1908.

The operating engineer in charge of this plant says it has given no trouble from the start. A 300-horsepower Corliss steam air compressor runs by the side of the gas engine. The engineer states that the gas plant has required much less attention during the fourteen months that it has been operating than the steam engine. The superintendent is very well pleased with the plant.

PLANT 59.

1908.

The assistant superintendent believes firmly in producer-gas power. When asked if there was anything about the plant he would like to improve upon he replied that he knew of nothing about the whole equipment of which he would ask better service. He maintains that the success of a producer-gas plant depends in great measure upon the men operating it. If the man at the producer knows what he is doing and the engineer is equally well adapted to his work, there will then be little trouble.

PLANT 60.

1908.

This plant has been in operation nearly ten months and is considered by the superintendent as very satisfactory. The superintendent has had some difficulty in obtaining competent men to handle the plant.

The coal consumption can probably be improved upon, as approximately 20 per cent of the coal charged into the producer passes through the grate unburned. The engine was operating very smoothly; in fact it is running as steadily as a steam engine. A portion of the time there is a heavy overload which has to be taken by the steam engine, but the gas engine and steam engine are run in parallel without difficulty. The superintendent thinks that eventually this steam engine will be replaced by a gas engine.

PLANT 61.

1908.

This plant has been in operation about a year and a half and it is giving excellent satisfaction. A new producer of 300 horsepower has recently been installed, having been in operation about three weeks at the time of this inspection. Before this last installation was made two producers of 150 horsepower each furnished the necessary gas. These have been in operation almost continuously since the installation of the plant and are in need of relining. The chief engineer feels so well satisfied with the plant that he says he would not hesitate to put in producer-gas power for any purpose.

PLANT 62.

1908.

This is an installation in the factory of a gas-producer manufacturer.

PLANT 63.

1908.

The president of the company feels that the secret of successful operation of producer-gas power plants is gas of uniform quality. In their business it is necessary to have constant-speed regulation. They found this difficult with producer-gas engines, due, he believes, to the lack of uniformity in the gas. He stated, however, that he would not hesitate to install a gas plant for any purpose in which absolutely constant speed is not required. He considers it a very economical power and feels that reliability depends largely upon the producer operator.

When the plant was first installed they experienced considerable trouble due to lack of knowledge. In his opinion, producer manufacturers fail properly to instruct operators of new plants. Since picking up the proper methods of manipulation they have had little difficulty and are well satisfied with the results that they are obtaining.

PLANT 64.

1906.

Only one engine was running during my visit; this seemed to be very steady in its operation.

Tar extractors were installed with this plant for operation in case bituminous coal should be used.

PLANT 65.

1906.

Difficulties.—They have had some trouble from clinkers; also, I believe, some from lampblack.

Remarks.—The superintendent did not feel absolutely sure about the power. He seemed to be well satisfied with the plant on the whole, but did not feel that it is absolutely reliable under all conditions. He was somewhat doubtful whether, in increasing the capacity of the power plant, to add more producer-gas units or to put in a steam plant to supplement the present gas plant. He seemed inclined to the additional producer-gas units provided he became positive of the absolute reliability of such power for continuous service, 24 hours per day.

The plant was running well at the time of my visit.

PLANT 66.

1906.

Most of the water gas (200 B. t. u.) is used for forges, etc., power being a secondary matter—a by-product, as it were.

The producer (air) gas generated is of about 90 B. t. u. heat value. The gas supplied to the engines is a mixture of the water and air gas in such proportions that its heat value is in the neighborhood of 115 to 130 B. t. u. per cubic foot.

The manager likes the plant well enough but feels that perhaps they could get more out of it than they do.

1908.

The works manager is on the whole very well satisfied with this plant. He encountered troubles at first, but after some experience learned how to overcome them. He does not feel that the producer manufacturers were able to give much help regarding the operation. The plant has been in nearly four years. The ash pile seemed to be small considering the amount of coal used. There was little real ash. The pile was composed mostly of clinkers varying in size from a man's fist to a nail keg, or even larger. There appeared to be very little carbon in the ash, but upon breaking up large clinkers numerous lumps of coke could be seen embedded.

The fires are drawn and the producers thoroughly cleaned each Sunday. On the whole the manager seems well satisfied with the plant, but feels that it is possible for them to get more out of it than they do.

PLANT 67.

1906.

The coal used is Pocahontas, which is delivered at the central station, and the various plants are supplied with the mixture as it comes from the central station. Owing to repeated handling the coal is reduced to a very fine condition.

The engine that was running while I was at the plant was pounding slightly. The engineers reported that they had broken exhaust levers occasionally, owing entirely to the carelessness of the operator.

The plant uses 34,000 cubic feet of water per day. Water is taken from the near-by brook instead of from the city service. The producer man was paid $16 per week.

In operating this plant at the present rate water gas is made only three times per day, and then only for two or three minutes at a time, long enough to fill the holder. The water gas is by-passed and mixed with the producer gas. A small portion only of the former is used.

The people in the vicinity objected to the noise of the exhaust. Several devices have been used to reduce this. At the time of my visit the plant was using a pit filled with broken rock, which seemed fairly satisfactory.

The engineer says that the men about the plant were greatly pleased with the producer at first, as if with a new toy, but after the novelty wore off their interest flagged. He says that the plant must be looked after and that there is a tendency on the part of the men to neglect it.

They have had occasional preignitions and back firing, but these have not been serious.

PLANT 68.

1908.

Although this plant is of the down-draft type, it is found necessary to "shoot the bed" only once in 24 hours as a rule, and sometimes only once in 2 days. The general manager of the company stated that the best coal obtainable is most satisfactory and economical, regardless of price. They have tried in this plant 20 or 25 different coals of a lower grade than that which they have selected as their best fuel. With the high-grade coal they usually operate one unit for two weeks, then cleaning it and operating the second unit during the second two weeks. With coals other than the kind especially selected for this plant they have usually found it impossible to run a unit longer than one week without cleaning. Some difficulty has been experienced in keeping the piston rods in such condition that they will not cut the stuffing boxes. Three of the engines are not regarded as satisfactory and are used only for carrying partial loads. They are apparently unreliable, as it was stated that they may run 5 minutes and they may run 24 hours. They require constant attention. The two larger engines are considered perfectly reliable. They were running with freedom at the time of this visit.

The first three years of this installation were marked by failure after failure. During this time apparently little help and few suggestions could be obtained from the manufacturers. It was a question of working out the difficulties at the plant itself. At the present time and for the past two years the installation has furnished reliable power, and at last the company is beginning to overcome the unsavory reputation gained for the plant during its early life. They are now furnishing power for several manuacturing plants and light for several villages up and down the valley. The manager believes that producer gas is the coming power, and feels that it is now possible to put up installations that will prove entirely reliable.

PLANT 69.

1906.

The producer manufacturers have not been called upon for any assistance since the plant was installed in 1900, but several changes have been made in the plant which have proved beneficial.

The gas-producer installation has been a process of development with this company, the original plant having been installed in 1900. One exhauster was run at that time by steam power and the other by a gas engine. After watching this gas engine for a time it was decided to try gas for power purposes. A tandem engine with rotary valves like those of a Corliss steam engine was installed. Grit would lift these valves from their seats, and the engine gave serious trouble. Finally, another type of engine was tried, and as it worked from the start with no difficulty, four additional engines of this make had been installed. They are expecting to install additional engines of the horizontal, double-acting type.

Straight water gas is used in many portions of the plant, but when low heats are required a mixture of 4½ parts producer gas (air gas) to 1 part water gas is used, giving a gas with a heat value of about 135 B. t. u. per cubic foot. For the engines 6 parts of air gas to 1 of water is used, giving a gas of about 115 B. t. u. per cubic foot.

Gas power has proved exceptionally economical for this plant, as most of the producer gas which had to be made was wasted before the installation of the engines.

The company believes thoroughly in this system of power, and each year more of the works is being supplied with gas power.

The plant requires proper care, which necessitates a good grade of men. For this reason the representative whom I saw believes that there is better economy in labor in a central power plant than in separate engine installations in various parts of the factory.

Every Sunday one engine is thoroughly cleaned, and the inlet valves and the mixing chambers in the others receive attention.

DEDUCTIONS FROM VISITS OF INSPECTION.

The deductions made from the visits in 1906 were as follows:

1. The plants as a whole are giving remarkable satisfaction considering the very brief period of development that has passed since the introduction of this type of power.
2. The most serious difficulty seems to arise from the lack of competent operators to run the plants rather than from defects or troubles inherent in the plants themselves.
3. Incompetent salesmen are undoubtedly to blame for serious misrepresentations and misunderstandings.
4. The neglect shown by some manufacturers in respect to their plants after they are installed and paid for has been noticeable, and the failure of manufacturers to give the purchasers or operators of plants full information regarding their construction and method of operating has certainly been detrimental to the business.

In 1909 the following modifications were made in the above statements:

1. Unchanged.
2. This situation still prevails, although there are many more competent operators to-day than three years ago. Time will eliminate this difficulty.
3. With the stronger companies this situation is greatly improved.
4. Experience has shown that such neglect produces serious troubles and financial loss to the manufacturer, and a very decided change for the better has developed in the past few years. There are, however, a few small concerns still operating in the producer field on what may be considered a false basis.

NUMBER AND DISTRIBUTION OF PRODUCER-GAS POWER PLANTS IN THE UNITED STATES.

Although a few scattered installations are reported to have been made prior to 1900, the period of systematic and general application of producer-gas power in this country began about 8 or 10 years ago. Owing to the fact that the dates of installation of many plants are not ascertainable, it is impossible to present the exact rate of growth either in number of installations or in horsepower. The relative rate is, however, approximately shown by figure 1 (p. 11). The relative rate of development of the plants using the three principal fuels, namely, anthracite, bituminous coal, and lignite, is shown by figure 2.

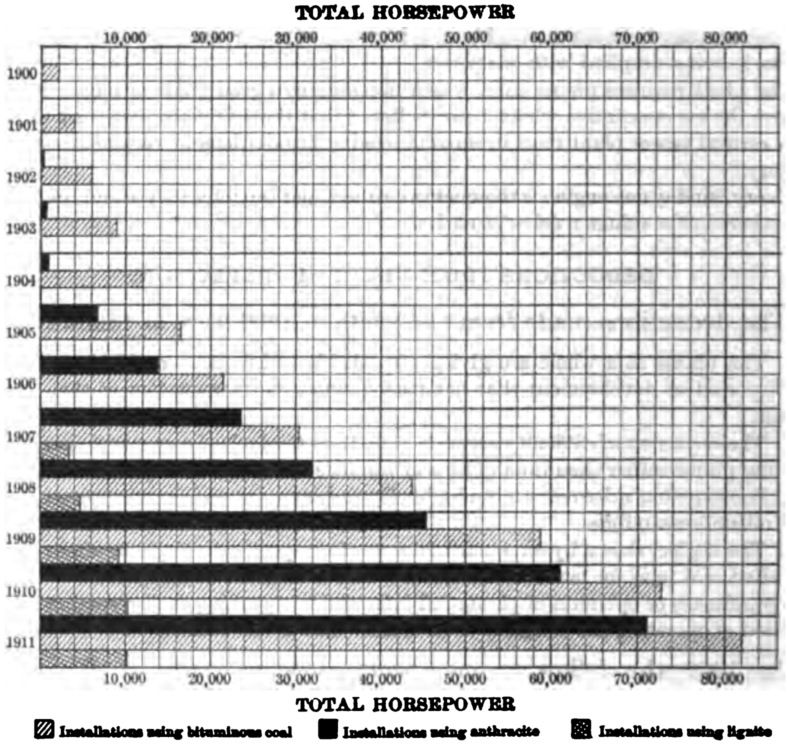

FIGURE 2.—Relative development of producer-gas installations in the United States using bituminous coal, anthracite, and lignite.

The demand for information regarding producer-gas power plants in actual commercial operation seems to be even more pronounced than in 1909, when the previous list of such installations was presented.

The interest of the engineering public to know the exact development of this type of power has led to a revision of the list presented in 1909, thus bringing it down to March, 1912. Through the courtesy of the manufacturers the previous list was corrected and the necessary additions made, except that three companies failed in 1912 to respond to requests for information.

The companies enumerated below supplied the material from which the tables following have been compiled. The abbreviations by which these manufacturers are indicated in the tables are given in parentheses.

Amsler Gas Power Co., Pittsburgh, Pa. (Amsler.)
Backus Water Motor Co., Newark, N. J. (Backus.)
Bruce-Macbeth Co., Cleveland, Ohio. (B. M.)
De la Vergne Machine Co., New York, N. Y. (De la V.)
Fairbanks-Morse Co., Beloit, Wis. (F. M.)
Gas Power Machinery Co., Los Angeles, Cal. (Grine-Nellis.)
Harvey, E. A., New York City, N. Y. (Harvey.)
Minneapolis Steel & Machinery Co., Minneapolis, Minn. (M. S. & M.)
Olds Gas Power Co., Lansing, Mich. (1909). (Olds.)
Otto Gas Engine Works, Philadelphia, Pa. (Otto.)
Power & Mining Machinery Co., Cudahy, Wis. (P. & M., or L. P.)
Smith Gas Power Co., Lexington, Ohio. (Smith.)
Standard Gas Power Co., Atlanta, Ga. (Akerlund.)
Struthers-Wells Co., Warren, Pa. (S. W.)
Syracuse Industrial Gas Co., Vernon, N. Y. (Syracuse.)
Weber Gas Engine Co., Kansas City, Mo. (1909). (Weber.)
Westinghouse Machine Co., East Pittsburgh, Pa. (West.)
Wile Gas Power Co., Rochester, N. Y. (1909). (Wile.)
Wood & Co., R. D., Philadelphia, Pa. (Wood.)

It is not claimed that the tables presented form a complete record of all the installations made by these companies. Certain restrictions have been imposed in preparing the tables, some of which should be mentioned to avoid misunderstanding or incorrect inference. They are as follows:

1. Some owners of plants object to making known the fact that they have such installations. Care has been exercised to prevent the insertion of the names of any such plants.

2. In certain instances the manufacturers have stated that their records are not sufficiently exact to enable them to make up complete lists.

3. One company does not approve of the presentation of a list of a great number of plants, and has restricted its own list to plants that have given unusual results, to those that are working in an unusual way or under extreme difficulties, and to those that show unusual economies or exceptional reliability.

The complete tabulation is given on pages 63 to 88.

SUMMARY.

It is probable that at the present time there are in the United States 900 or 1,000 producer-gas power plants, ranging in size from 15 horsepower to several thousand horsepower. The data procured from the lists supplied by the manufacturers both in 1909 and in 1912 are summarized in the following table according to the type of fuel used, the plants being classified as to whether they are above or below 500 horsepower:

Summarized data relative to producer-gas power plants in the United States, March, 1912.

	Number of plants.			Horsepower.									Percentage of total number.		Percentage of total horsepower.	
				Total.			Average.		Minimum.		Maximum.					
	1909	1912	Percentage increase.	1909	1912	Percentage increase.	1909	1912	1909	1912	1909	1912	1909	1912	1909	1912
Anthracite coal:																
Over 500 horsepower........	8	29	263	7,550	25,825	242	950	890	600	520	1,500	1,800	....	....	....	....
500 horsepower or less........	407	581	43	40,550	63,645	57	100	110	15	15	500	500	....	....	....	....
	415	610	47	48,100	89,470	86	116	146	15	15	1,500	1,800	88	84.5	43	47.8
Bituminous coal:																
Over 500 horsepower........	20	40	100	49,000	76,890	57	2,450	1,920	750	600	6,000	9,000	....	....	....	....
500 horsepower or less........	17	37	118	5,150	9,725	89	300	262	35	25	500	500	....	....	....	....
	37	77	108	54,150	86,615	60	1,460	1,120	35	25	6,000	9,000	8	10.7	49	46.3
Lignite:																
Over 500 horsepower........	3	3	0	7,275	7,275	0	2,430	2,430	525	525	3,750	3,750	....	....	....	....
500 horsepower or less........	19	29	53	1,725	2,955	71	90	102	25	25	250	350	....	....	....	....
	22	32	45	9,000	10,230	14	410	320	25	25	3,750	3,750	4	4.4	8	5.4
Wood:																
Over 500 horsepower........	0	0	....	0	0	....	......	......	....	....	......	......	....	....	....	....
500 horsepower or less	....	1	....	......	500	....	......	500	....	500	......	500	....	0.1	....	0.3
Oil:																
Over 500 horsepower........	0	0	....	0	0	....	......	......	....	....	......	......	....	....	....	....
500 horsepower or less........	....	2	....	......	325	....	......	163	....	100	......	225	....	0.3	....	0.2
Total........	474	722	52	111,250	187,140	68	235	260	15	15	6,000	9,000	100	100	100	100

The most conspicuous facts derived from an inspection of the foregoing table are:

1. During the past three years the number of anthracite plants of over 500-horsepower rating has increased 263 per cent, and the total horsepower represented by these plants has increased in the same period 242 per cent.

2. During the same period the number of bituminous-coal plants of 500-horsepower rating or less has increased 118 per cent, and the total horsepower represented by these small bituminous-coal plants has increased 89 per cent.

3. At the present time producer-gas plants representing nearly 85 per cent of the total number of installations in this country are operating on anthracite.

4. Of the total horsepower listed approximately 48 per cent is derived from anthracite and nearly 52 per cent from bituminous coal and lignite.

5. In 1909 the bituminous-coal plants averaged 12.5 times the size of the anthracite plants, but the introduction of the larger anthracite plants and of the smaller bituminous-coal plants makes the ratio for 1912 about 7.5 to 1.

It is gratifying to note the development of the small bituminous-coal producer, and an examination of the complete list of installations

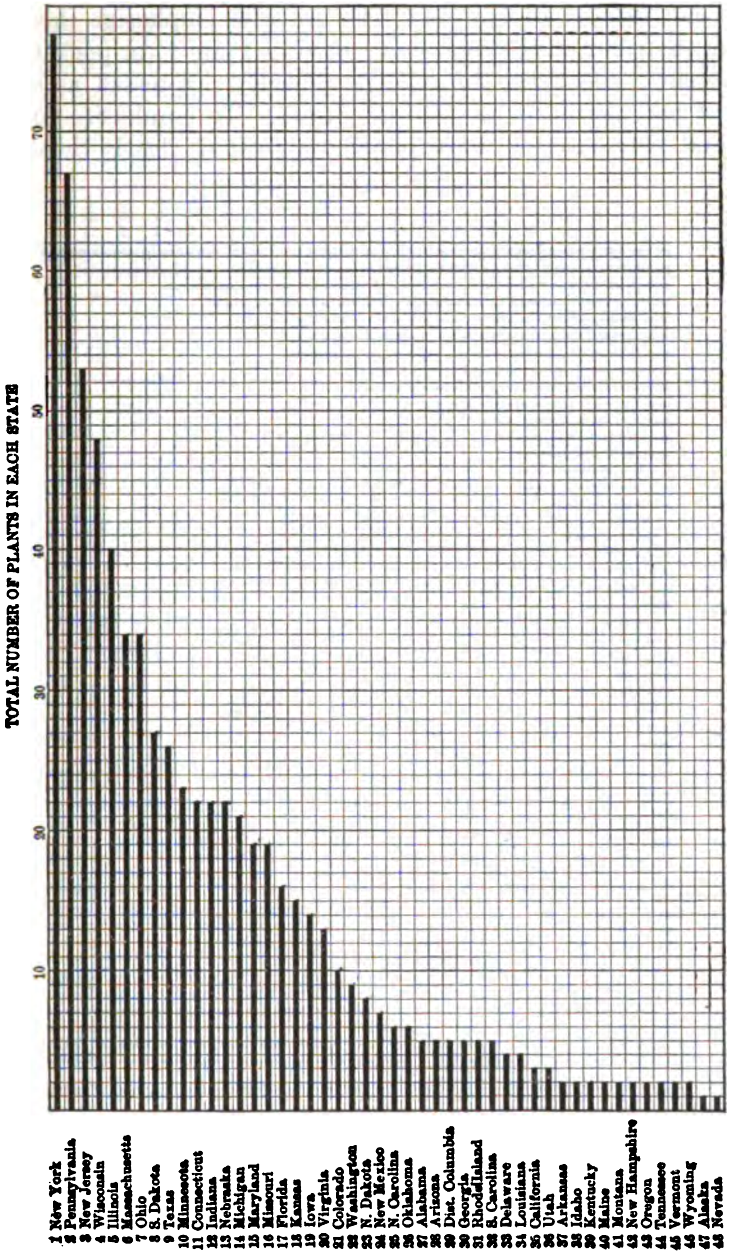

FIGURE 3.—Total number of producer-gas power-plant installations in each State.

reveals several suction plants operating on bituminous coal. The need of small producers of this type has been keenly felt, and their development is one of the most important steps in the producer field.

An examination of the complete list of producer-gas plants shows the very general distribution of this type of power throughout the country. It is apparent that the application of the anthracite producer is not limited to the East. In order to emphasize this geographical distribution the map designated as Plate I (in pocket) has been prepared, based on the relative capacity, expressed as horsepower, of the plants in the various States. To emphasize further the general distribution of these plants and to show clearly the distribution during the past three years as contrasted with that during the period preceding 1909, the map is presented in two colors. The installations made prior to 1909 are represented in black, and those made during the past three years are indicated in red.

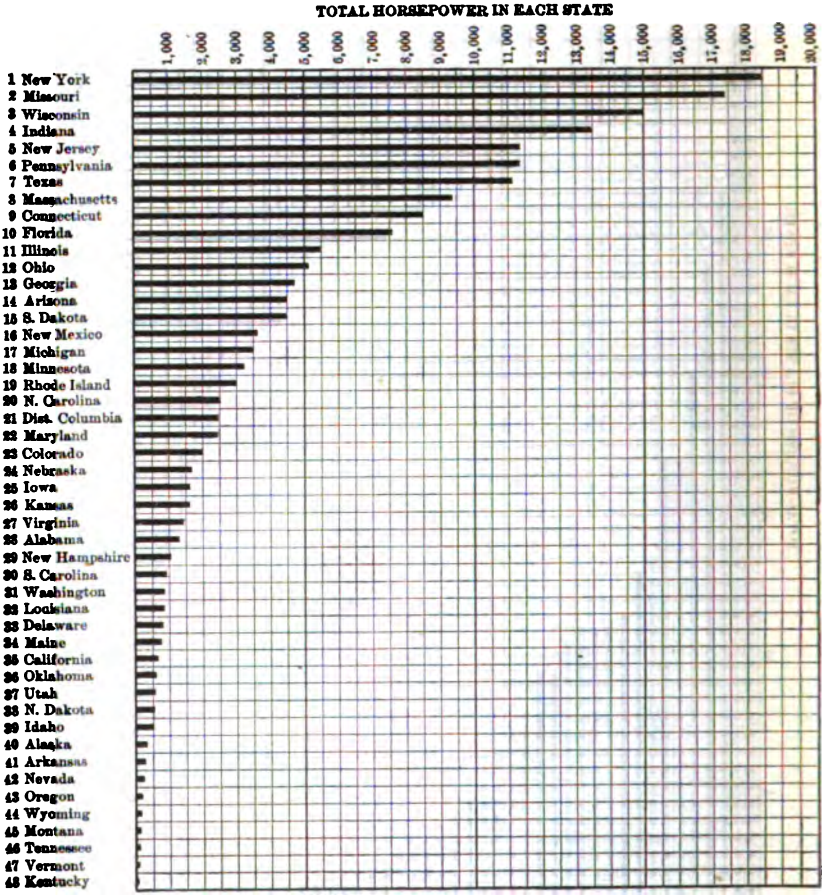

FIGURE 4.—Total horsepower of producer-gas power-plant installations in each State.

Figures 3 and 4 present in another form the data shown on the map. These figures show, respectively, the total number and the total horsepower in each State represented in the complete list of plants prepared from the data supplied by the manufacturers.

BLAST-FURNACE AND COKE-OVEN GAS POWER PLANTS.

So closely allied to producer-gas power plants are blast-furnace and coke-oven gas power plants that a tabulation of the principal installations of this type in this country is presented.

Acknowledgment is made to the following companies who very kindly supplied the necessary information:

Allis-Chalmers Co., Milwaukee, Wis.
American Iron & Steel Co., Lebanon, Pa.
American Steel & Wire Co., Cleveland, Ohio.
American Steel & Wire Co., Pittsburgh, Pa.
Buckeye Engine Works, Salem, Ohio.
Carnegie Steel Co., Pittsburgh, Pa.
Cornwall Ore Bank Co., Cornwall, Pa.
Empire Gas & Electric Co., Geneva, N. Y.
Illinois Steel Co., Chicago, Ill.
Lackawanna Steel Co., Buffalo, N. Y.
National Tube Co., Pittsburgh, Pa.
Pennsylvania Steel Co., Steelton, Pa.
Snow Steam Pump Co., Buffalo, N. Y.
Westinghouse Machine Co., East Pittsburgh, Pa.

With the exception of the pioneer company, the Lackawanna Steel Co., which installed 40,000 horsepower between 1900 and 1905, the principal development in this particular field in the United States has been during the past five years. The aggregate horsepower of these installations is 339,280. The tabulation follows.

Power installation in the United States using blast-furnace gas and coke-oven gas.

Location of plant.	Firm.	Date of installation.	Use of power.	Fuel.	Make of engine.	Horsepower of each unit.	Number of units.	Total horsepower.
Illinois:								
Joliet	Illinois Steel Co	1912	Electric power for mills, furnaces, etc.	Blast-furnace gas	Allis-Chalmers	4,300	Three	12,900
South Chicago	do	1907–8	Electric power for mills, furnaces, cement plants, etc.	do	do	3,500	Four	14,000
Do	do	1910–11	Blowing blast furnaces	do	2 Snow 2 Allis-Chalmers 2 Bethlehem	3,600 2,200 2,200	Six	16,000
Do	Peoples' Gas Light & Coke Co.	1912	Gas exhausters	Coke-oven gas	Buckeye	320	Two	640
Indiana:								
Gary	Illinois Steel Co	1908	Electric power for mills, furnaces, etc.	Blast-furnace gas	Allis-Chalmers	3,875	Nine	34,875
Do	do	1908	Blowing blast furnaces	do	Westinghouse	2,900	Eight	23,200
Do	do	1909	Electric power for mills, furnaces, etc.	do	Allis-Chalmers	3,875	Eight	31,000
Do	do	1909	Blowing blast furnaces	do	do	3,500	Eight	28,000
Do	do	1911	Electric power for mills, furnaces, etc.	do	do	4,300	Six	25,800
New York:								
Geneva	Empire Gas & Electric Co		550 horsepower used in local plant; gas also sold for 100 engines of 10 to 100 horsepower.	By-product coke-oven gas of 600 to 650 B. t. u.	2 Alberger 1 Westinghouse	300+150 +100	Three	550
Lackawanna	Lackawanna Steel Co	1900–1905	Electric power	Blast-furnace gas	Koerting 2-cycle	1,000	Eight	8,000
Do	do		Blowing engines	do	do	2,000	Sixteen	32,000
Ohio:								
Cleveland	American Steel & Wire Co. (central furnaces).	1908	Electric power; four 1,180-kilowatt A. C. generators, 25-cycle, 3-phase, 13,200 volts.	Blast-furnace gas, 90 B. t. u. per cubic foot.	Allis-Chalmers	2,250	Four	9,000
Do	do	1911	Blowing furnaces; each engine at 60 revolutions per minute has a capacity of 40,000 cubic feet of free air per minute.	do	do	3,900	Two	7,800
Youngstown	Carnegie Steel Co. (Ohio works).	1908	Driving A. C. generator	Blast-furnace gas	William Todd	1,740	One	1,740
Do	do	1909	Blowing blast furnaces	do	do	3,500	Four	14,000
Do	do	1909	Driving A. C. generators	do	Snow	3,600	Four	14,400
Pennsylvania:								
Bessemer	Carnegie Steel Co. (Edgar Thompson works).	1907	Blowing blast furnaces	do	Westinghouse	2,040	Two	4,080
Do	do	1907	Driving A. C. generator	do	do	2,820	One	2,820

Duquesne	Carnegie Steel Co. (Duquesne works).	1910	Blowing blast furnaces	do	Snow	2,310	Four	9,240
Do	do	1910	Driving A. C. generators	do	do	3,600	Two	7,200
Lebanon	American Iron & Steel Mfg. Co.	1906	Electric	Coke-oven gas when available; producer gas at other times.	Westinghouse	500	One	500
Do	Pennsylvania Steel Co. (Cornwall Ore Bank Co.).	1908-9	Electricity for use at Cornwall.	By-product coke-oven gas from Semet-Solvay plant of Pennsylvania Steel Co. at Lebanon.	do	1,200	Three	3,600
McKeesport	National Tube Co	1907	250-volt direct current distributed to motors throughout the mill for driving the machinery.	Blast-furnace gas taken from any or all of the four blast furnaces at the works.	Allis-Chalmers	1,500	Two	3,000
Rankin	Carnegie Steel Co. (Carrie furnaces).	1908	Blowing blast furnaces	Blast-furnace gas	do	3,500	Four	14,000
Do	do	1909	Driving A. C. generators	do	do	3,500	Three	10,500
Do	do	1911	do	do	Bethlehem	3,600	Two	7,200
Steelton	Pennsylvania Steel Co	1910	Blowing engine	do	Allis-Chalmers	2,250	One	2,250
Wisconsin:								
Milwaukee	Illinois Steel Co	1907	Electric power for mills, furnaces, etc.	do	do	985	One	985

Producer-gas power installations in the United States.

[Abbreviations: Act., acting; anth., anthracite; bit., bituminous; cyl., cylinder; d. d., down-draft; dble., double; horiz., horizontal; lig., lignite; n. b., nonbituminous; p., pressure; s., suction; semi-a., semianthracite; semi-b., semibituminous; sing., single; tan., tandem; vert., vertical. For the full names of manufacturers, see list on p. 59.]

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Alabama:												
Birmingham	White Blakesley Mfg. Co.			S.	50	50		Amsler				
Farley	International Harvester Co.	Belt drive	1907	S.	60	60	Anth	Smith	Rathbun	Vert	60	60
Greenville	Southern Cotton Oil Co.			S.		150	Bit	Wood				
Montgomery	do	Line-shaft drive.	1910		300 190 250	990	Bit	West	West	Horiz Vert Vert Horiz	190 190 190 300	870
University	University of Alabama		1909		35	35	Anth. and lig	F. M	F. M	Horiz	35	35
Alaska:												
Juneau				S.	250	250	Anth	Weber	Weber	3-cyl. vert	250	250

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Arkansas:												
Camden	Camden Mill Co.	Electric light	1909	S.	150	150	Lig	M. S. & M.	Muenzel	Horiz	200	200
Do	Camden Water & Light Co.	Light and waterworks.	1909	S.	75	75	Anth	F. M	F. M	Horiz	50	100
Arizona:												
Douglass	El Gobo Mining & Milling Co.		1905	S.	77	77	Anth	L. P	Crossley	1 cyl	77	77
Kingman	Cerbat Mountain Mining Co.			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Do	Stockton Mining Co.			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Morenci	Detroit Copper Mining Co.		1897 1901 1905	D. d.		4,000	Bit	L. P	Crossley			
Yuma	U. S. Reclamation Service.			S.		225	Oil		Weber	3-cyl. vert	125+100	225
California:												
Alamo	Alamo Electric Light & Power Co.		1906	D. d.	500	500	Wood	L. P	Crossley	1-cyl	120	360
Hollywood	Wm. C. Fry	Pumping water.	1911	P.	100	100	Crude oil	Grine-Nellis	F. M	2-cyl	100	100
Los Angeles	Hermosa Mining Co			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Colorado:												
Denver	Delos A. Chappell		1907	S.	45	45	Anth	Otto				
Do	Colorado Milling & Elevator Co.		1908	S.	100	100	Lig	F. M	F. M	Vert	100	100
Do	Western Chemical Co.		1908–9		175	525	Lig	West	West	Vert	140+190	330
Golden	Colorado School of Mines		1910		150	150	Lig	West	West	Vert	118	118
Greeley	Home Light & Power Co		1907	N. b.	150	300	Anth	Olds	Olds	1-cyl. horiz	75	300
Palisades	J. R. Gordon		1910		200	400	Anth	F. M	F. M	Vert	200	400
Rocky Ford	City of Rocky Ford			S.		200	Anth	Weber	Weber	3-cyl. vert	100	200
Do	Dr. Fenton		1906	N. b.	75+35	110	Anth	Olds	Olds	1-cyl. horiz	65+35	100
Silver Cliff	Gladstone Reduction Co.	Cyanide mill	1907	S.	50	50	Anth	F. M	F. M	Horiz	35	35
Twin Lakes	Ruby Mines Development Co.		1907	N. b.	75	75	Anth	Olds	Olds	1-cyl. horiz	75	75
Connecticut:												
Beacon Falls	Homer D. Bronson Co.		1910	S.	75	75	Anth	Smith	Weber	Vert	75	75
Bridgeport	Bridgeport Malleable Iron Co.		1907	D. d.	375	375	Bit	L. P	Snow	Twin tan Sing. tan	250 125	375
Do	Columbia Nut & Bolt Co		1907	S.	150	150	Anth	Wile	Alberger	Horiz	150	150
Do	Handy & Harmon		1907	S.	100	100	Anth	L. P	Snow	Sing. tan	100	100
Do	A. H. Nilson Machine Co		1906	S.	60	60	Anth	Wile	Jacobson	Horiz	25	25

Do	Van Auken Motor & Machine Works.	Belt drive	1907	S.	35	35	Anth	Smith	Rathbun	Vert	35	35
Bristol	New Departure Mfg. Co		1905–7	D. d.	750	1,500	Bit	L. P	Snow & Crossley.		275	550
Coscob	Miamus Motor Works		1909		100	100	Anth	F. M	F. M	Vert	100	100
Elmwood	Whitelock Coil Pipe Co		1906	D. d.	500	500	Bit	L. P				
Georgetown	Gilbert & Bennet Mfg. Co.		1909	S.	30	30	Anth	Otto				
Do	do	Belted power	1907				Anth	Wood	West	Vert	140	140
Do	do		1909				Anth	Wood	West	Vert	270	270
Mianus	Mianus Motor Works		1907	S.	45	45	Anth	Otto				
Middletown	W. H. Chapman		1905	S.	100	100	Anth	Otto				
Do	Rogers & Hubbard		1909	S.	150	150	Anth	Otto				
New Haven	Geometric Tool Co		1907	S.	100	100	Anth	Smith	West	Vert	66	132
Do	Winchester Repeating Arms Co.	Electric Generator.	1900 1902 1908	D. d.	1,000 2,000 1,000	4,000	Bit	L. P	West	Vert. and horiz	100(1) 165(5) 500(4)	2,925
Plantsville	Blakeslee Forging Co	Belted power	1907	S.	100	100	Anth	Smith	Nash	Vert	100	100
Putnam	John M. Dean	Factory drive	1910	S.	100	100	Anth	Gas Mach. Co	B. M	4-cyl. vert	100	100
Seymour	Fowler Nail Co	Power	1911	S.	150	150	Anth	Smith	Nash	Vert	135	135
Shelton	Griffin Button Co		1907	S.	80	80	Anth	Wile	Rathbun	Vert	85	85
Do	Radcliffe Bros		1907	P.	125	125	Anth	West	West	Vert	50	50
Tracy, Yalesville.	Jennings & Griffin Mfg. Co.	Factory power	1906	S.	100	100	Anth	F. M	F. M	Vert	100	100
Waterbury	Blake & Johnson		1909				Anth	West	West		60	60
Delaware:												
Christiana Creek.	American Pipe & Construction Co.			S.		200	Anth	Wood				
Delaware City	American Power Co		1910		100(3)	300	Anth	F. M	F. M	Vert	100(2),43(1)	243
Ruthby	Delaware Water Co		1907				Anth	West	West	Vert	85	170
Selbyville	Delware Light & Ice Co		1910	S.	150	150	Anth	Otto	Otto		150	150
District of Columbia:												
Washington	L. P. Dorsett Co		1909	S.	100	100	Anth	F. M	F. M	Vert	100	100
Do	Firth-Sterling Steel Co		1906 1908	P.	175 175 350	700	Anth	West	West	3-cyl. vers	164 164 190	518
Do	Review & Herald Publishing Co.		1906	S.	75	75	Anth	F. M	F. M	Vert	65	65
Do	Washington Market Co		1909		300	900	Bit	West	West	Horiz. and vert	300(2) 100(1) 140(1)	540
Do	Washington Steel & Ordnance Works.		1906– 1908		175(2), 350(1)	700	Anth	West	West	Vert	165(2), 190(1)	520
Florida:												
Bartow	Florida Phosphate Co		1908	D. d.	750	750	Bit	L. P	Snow		150 250 300	750
Do	State Phosphate Co	Mine power	1912	D. d.	1,000	1,000	Bit	L. P	Allis-Ch			
Do	Swift & Co		1907	D. d.	1,000	1,000	Bit	L. P				
Holder	J. Buttenbach Co	Electric light	1906	S.	200	200	Anth	F. M	F. M	Vert	200	200
Inglis	Auchincloss Bros		P.	P.	350	350	Bit	Wood				
Do	Baker Chemical Co	Belted power	1905				Bit	Wood	West	Vert	50+165	215

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Florida—Contd.												
Jacksonville	Gibbs Gas Engine Co	Machine shop	1909	S.	25	25	Bit	Akerlund	Otto	Horz	25	25
Do	E. O. Painter Fertilizer Co.	Fertilizer works.	1906	S.	150	150	Anth	F. M	F. M	Vert	150	150
Jasper	U. R. Horne	Electrical	1906	S.	100	100		F. M	F. M	Horiz	100	100
Miami	George F. Cook Co	Dredge	1911	S.	200	200	Bit	Akerlund	F. M Hagan	3-cyl. vert Twin horiz	150 50	200
Newberry	Albion Mining & Mfg. Co.	Mining	1908	S.	200	200	Anth	F. M	F. M	Vert	200	20
Ocala	Spencer & Smith		1905	S.	50	50	Anth	F. M	F. M	Vert	43	43
Pebbledale	Pierce Phosphate Co	Mine power	1910	D. d.			Bit	L. P	West	Horiz	1,150	1,150
Pierce	do	Mine power	1910	D. d.	1,000	1,100	Bit	L. P	West			
St. Cloud	Seminole L. & I. Co		1910	S.	100	100	Anth	F. M	F. M	Vert	100	100
Tiger Bay	Palmetto Phosphate Co		1909	P.		1,050	Bit	Wood	Allis Chalmers			
Georgia:												
Atlanta	Fulton County almshouse.	Pump and light.	1911	S.	750	1,500	Bit	Akerlund	Otto	Horiz	50	50
Do	W. R. Polk	Electric light and power.	1912	S.	150	150	Bit	Akerlund	Miller	Twin horiz	100	100
Savannah	Southern Cotton Oil Co	Power and fuel.	1909-1911		350(2) 300(2)	1,300	Bit	West	West	Horiz	575	575
Union Point	Union Mfg. Co	Cotton mill	1910	S.	250	250	Bit	Akerlund	Otto	Horiz	160+75	235
Waycross	Ware Company Light & Power Co.	Town light	1910-1911	D. d.	750	1,500	Bit	L. P	A. C			
Idaho:												
Boise	Faris-Keal Construction Co.	Dredging	1906	S.	150	150	Anth	F. M	F. M	Vert	150	150
Hayden Lake	Interstate Irrigation Co			S.	250	250	Anth	Weber	Weber	3-cyl. vert	250	250
Illinois:												
Alton	Illinois Glass Co	Electric transmission.	1910	S.	200	400	Bit	Smith	Rathbun	Vert	200	400
Do	do	Gas for heating and electric trans.	1911	S.	300	600	Bit	Smith	Rathbun	Vert	400	400
Antioch	H. H. Kellogg	Electric lighting plant.	1907	S.	100	100	Anth	Smith	West	Vert	100	100
Arlington Hts	Brav & Kates		1907	N. b.	90	90	Anth	Olds	Olds	1-cyl. horiz	75	75
Bowen	E. E. Bennett		1909		75	75	Anth	F. M	F. M	Horiz	50	50
Chicago	Chlopeck Fish Co	Electric lighting and refrigeration.	1907	S.	35	35	Anth	Smith	Buffalo	Horiz. tan. sing. act.	35	35
Do	Cole Mfg. Co	Foundry	1905	S.	75	75	Anth	Otto				
Do	Cullman Wheel Co	Factory drive	1909	S.	100	100	Anth	Tait	B. M	2-cyl. vert	55	55

Do.	A. B. Dick Co.	Light and power.	1906	S.	110+55	165	Anth.	M. S. & M.	Muenzel.	Horiz. sing. act.	110+55	165
Do.	Goodman American Ice Cream Co.		1909	S.	100	200	Anth.	Wile.	B. M.	4-cyl. vert.	115+100	215
Do.	Oscar Heineman.		1907	S.	125	125	Anth.	West.	West.	3-cyl. vert.	100+38	138
Do.	Home Stove Works.			S.		205	Anth.	Weber.	Weber.	3 and 2-cyl. vert.	80+125	205
Do.	Illinois Fiber Box Co.		1909	S.	60	60	Anth.	Wile.	B. M.			
Do.	Mathias Klein & Son.	Factory.	1907	S.	55	55	Anth.	M. S. & M.	Muenzel.	Horiz sing. act.	55	55
Do.	Manhattan Lumber Co.			S.	40	40		Backus.				
Do.	Martin & Martin.	Electric light and power.	1906	S.	75	75	Anth.	F. M.	F. M.	Horiz.	50	50
Do.	William L. Rudd Co.		1909	S.	125	125	Anth.		B. M.	4-cyl. vert.	100	100
Do.	Seng Co.			S.		150	Anth.	Wood.				
Do.	Terminal Garage.	Electric light and power.	1910	S.	85	85	Anth.	Smith.	Nash.	Vert.	85	85
Do.	Tuthill Spring Co.	Belted power.	1911	S.	100	100	Anth.	Smith.	Thompson.	Vert.	100	100
Do.	Vermont Marble Works.	Machinery.	1906	S.	150	150	Anth.	F. M.	F. M.	{1 vert. {1 horiz.	65 50	} 115
East St. Louis.	Municipal pumping plant.		1909	S.		450	Bit.	Wood.	Rathbun.			
Elburn.	Municipal electric light plant.		1911	S.	25	25	Anth.	Smith.	I. H. C.	Vert.	25	25
Elgin.	American Tower & Tank Co.	Belted power.	1908	S.	35	35	Anth.	Smith.	Nash.	Vert.	35	35
Elmhurst.	Elmhurst Spring Water Co.		1906	S.	27	27	Anth.	Otto.				
Gibson City.	Central Electric Heat, Light & Power Co.		1911	S.	100	200	Anth.	Smith.	Nash.	Vert.	100	200
Harvard.	Harvard Electric Light Co.			S.	250	250	Anth.	Weber.	Weber.	4-cyl. vert.	250	250
Hoopestown.	Hoopestown Gas & Electric Co.	Electric light plant.	1908–9	S.	150	300	Anth.	M. S. & M.	Muenzel.	Horiz. sing. act.	280+100	380
Joliet.	Franklin Steel Works.	Belt drive.	1906	S.	60	60	Anth.	Smith.	Rathbun.	Vert.	60	60
Do.	Illinois Metal Refining Co.	Electric transmission.	1910	S.	150	150	Bit.	Smith.	Alberger.	Horiz.	150	150
McHenry.	McHenry Electric Service Co.		1909	S.	125	125	Anth.	Wile.	B. M.	Vert.	115	115
Marengo.	Marengo Electric Co.			S.	60	60	Anth.	Weber.	Weber.	2-cyl. vert.	60	60
Oglesby.	Oglesby Electric Light Plant.	Electric light.	1910	S.	35	70	Anth.	Smith.	I. H. C.	Vert.	35	70
Olney.	Schultz Seed Co.		1908	N. b.	50	50	Anth.	Olds.	Olds.	1-cyl. horiz.	50	50
Pekin.	Pekin & La Marsh Dredging Co.			S.	100	100	Anth.	Weber.	Weber.	3-cyl. vert.	100	100
Quincy.	Stationers Mfg. Co.			S.	150	150	Anth.	Weber.	Weber.	2-cyl. vert.	150	150
Rockford.	Cotta Transportation Co.		1909		75	75	Anth.	F. M.	F. M.	Horiz.	50	50
Do.	Mechanics Machine Co.	Machine shop.	1905	S.	50	50	Anth.	F. M.	F. M.	Horiz.	50	50
Urbana.	University of Illinois.		1905	S.	45	45	Anth.	Otto.				
Villa Grove.	Villa Grove Electric Co.		1909	S.	100	100	Anth.	F. M.	F. M.		100	100
Wheaton.	Municipal pumping plant.		1911	S.	75	75	Anth.	Wood.	Nash.			

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Indiana:												
Alexandria	Penn American Plate Glass Co.				400	2,000	Bit.	Wood & Harvey.	Koerting		600	1,800
Anderson	Nicholson File Co.		1908		1,000	2,000	Bit.	Harvey	Alberger		150	150
Brazil	Brazil Gas Co.			S.	100	100	Anth.	Weber	Weber	3-cyl. vert.	100	100
Decatur	Ward Fence Co.	Belted power.	1908	S.	50	50	Anth.	Smith	Nash	Vert.	50	50
Etna Green	T. M. Jones	Electric lighting.	1903	S.	35	35	Anth.	Smith	Wayne	Horiz. sing. act.	35	35
Do.	Town of Etna Green	Electric light and water.	1903	S.	35	35	Anth.	Smith	Jacobson	Horiz.	35	35
Fort Wayne	Dudlo Mfg. Co.	Electric transmission and gas for heating.	1911	S.	125	125	Bit.	Smith	Elyria	Horiz.	28	28
Do.	Economy Glove Co.		1905	S.	35	35	Anth.	Smith	Wayne	Horiz. sing. act.	20+15	35
Do.	S. Freiberger & Bro.		1905	S.	27	27	Anth.	Otto				
Greenfield	William Mitchell Printing Co.		1908	S. and P.	125	125	Anth.	Wile	Riverside	Horiz.	75	75
Indianapolis	Capital Gas Engine Co.		1905	S.	25	25	Anth.	Smith	Capital	Horiz. sing. act.	25	25
Do.	Indianapolis Candy Co.	Power and pumping.	1905	S.	50	100	Anth.	F. M.	F. M.	Horiz.	50	100
Do.	International Machine Tool Co.	Electric transmission.	1907	S.	100	100	Anth.	Smith	Rathbun	Vert.	115	115
Do.	Langsenkamp Bros. & Wheeler.	Direct-connected.	1907	S.	100	100	Anth.	Smith	Rathbun	Vert.	100	100
Do.	Langsenkamp-Wheeler Brass Works.		1909–11		1-250 4-350	1,650	Bit.	West.	Rathbun.			
Kokomo	Kokomo Nail & Brad Co.	Electric transmission.	1909	S.	125	125	Anth. or bit.	Smith	Riverside	Horiz.	125	125
Do.	Pittsburgh Plate Glass Co.		1909	D. d.	4,500	4,500	Bit.	L. P.	Allis-Chalmers			
Do.	do.	Factory power	1910	D. d.	1,500	1,500	Bit.	L. P.	Allis-Chalmers			
Lafayette	Purdue University	Experiments.	1905	S.	50	50	Anth.	F. M.	F. M.	Vert.	43	43
Peru	City of Peru	Pumping plant.	1908	S.	150	300	Semi-b.	Smith	Peru	Vert.	300	300
Do.	Model Gas Engine Works.	Belted power.	1908	S.	150	150	Anth.	Smith	Model	Vert.	135	135
Do.	Otis Elevator Co.	Electric transmission.	1909	S.	150	150	Anth. or bit.	Smith	Alberger	Horiz.	150	150
Sheridan	City of Sheridan	Lighting and waterworks.	1908	S.	150	150	Anth.	F. M.	F. M.	Vert.	150	150

Iowa:											
Algona	City of Algona	City lights	1906	S.	150	150	Anth.	F. M.	F. M.	Vert.	150	150
Allerton	Town of Allerton	Electric lights.	1910	S.	100	100	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Ames	Iowa State College	Experiments.	1907	S.	50	50	Anth.	F. M.	F. M.	Vert.	43	43
Burlington	O. M. Burrus & Bro.	Granite shop.	1907	S.	60	60	Anth.	Smith	Rathbun	Vert.	60	60
Council Bluffs.	Kimble Bros.	Machinery	1904	S.	27	27	Anth.	Otto				
Danbury	City of Danbury	Waterworks.	1910	S.	75	75	Anth.	Smith	Foos	Horiz.	60	60
Des Moines	Bentley & Olmstead Co.		1910	S.	75	75	Anth.	F. M.	F. M.	Horiz.	50	50
Hartley	Town of Hartley	Electric lighting.	1909	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Monticello	City of Monticello		1910	S.	150	150	Anth.	Smith	Nash	Vert.	150	150
Red Oak	The Replogle Co.	Power	1908	S.	120	120	Anth.	Otto				
Strawberry Pt.	Town of Strawberry Pt.		1910	S.	100	100	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Union	Union Electric Power Co.	Electric lights.	1909	S.	65	65	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	65	65
Waterloo	Iowa Dairy Separator Co.		1909	S.		275	Bit.	Wood	Rathbun			
Waukon	Missouri Iron Co.		1908	P.	350	350	Anth.	West	West	Vert.	190	380
Kansas:											
Baldwin	City electric light plant.		1907	N. b.				Olds	Olds	1-cyl. horiz.	25+75	100
Do.	Town of Baldwin			S.	125	125	Anth.	Weber	Weber	3-cyl. vert.	125	125
Dodge City	Midland Water, Light & Ice Co.		1908	S.	150	150	Semi-a.	Smith	Buckeye	Twin. sing. act.	180	180
Downs	Downs Electric Light & Power Co.	Electric light.	1907	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Galena	Galena Foundry & Machine Co.			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Lawrence	University of Kansas	Demonstration plant and experimental laboratory.	1909		75	75	Semi-b.	Smith		Sing. act.		
Do.	do.	Experimental.	1909	S.	75	75	Bit.	Smith				
Lincoln Center.	City of Lincoln Center	Electric lights and water works.	1906	S.	100	100	Anth.	F. M.	F. M.	Vert.	100	100
Manhattan	Kansas State Agricultural College.	Experimental.	1908	S.	100	100	Bit.	Smith				
Merriam	Shawnee Construction Co.			S.	125	125	Anth.	Weber	Weber	3-cyl. vert.	125	125
Minneapolis	Farmers' Electric & Alfalfa Mill Co.	Milling and elevators.	1908	S.	100	100	Anth.	F. M.	F. M.	Vert.	100	100
Ottawa	City of Ottawa			S.	125	125	Anth.	Weber	Weber	3-cyl. vert.	125	125
Parsons	Parsons Water Co.			S.	125+80	205	Anth.	Weber	Weber	3 and 2-cyl. vert.	125+80	205
Sterling	G. A. Morris		1909	S.	100	100	Anth.	F. M.	F. M.	Vert.	100	100
Whitewater	Whitewater Alfalfa Milling Co.		1908	S.	60	60	Semi-a.	Smith	Buckeye	Horiz. tan.	60	60
Wichita	United Sash & Door Co.		1906	N. b.	125	125	Anth.	Olds	Olds	1-cyl. horiz.	75+50	125
Kentucky:											
Owenton	W. E. Arnold	Flour mill	1907	S.	35	35	Anth.	Smith	Columbus	Horiz.	35	35
Williamstown.	J. M. Riley	Flour mill	1907	S.	35	35	Anth.	Smith	Columbus	Horiz.	35	35

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Louisiana:												
Gramercy	Colonial Sugar Co		1911	S.	70	70	Anth	Otto				
Gretna	Southern Cotton Oil Co	Belted power	1907	P.		500	Bit	Wood	West	Vert	60+140+270	470
Plaquemine	Plaquemine Electric Light & Power Co.	City lights and waterworks.	1905	S.	150	250	Anth	F. M	F. M	Horiz	150	250
			1907	S.	100					Vert	100	
Shreveport	Hamitzer & Busby			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Maine:												
Eastport	Seacoast Canning Co			P.		700	Anth	Wood				
Norway	Norway waterworks		1906	N. b.	65	65	Anth	Olds	Olds	1-cyl. horiz	65	65
Maryland:												
Baltimore	Baltimore Plate Ice Co	Refrigeration plant.	1909	S.	200	400	Anth	Smith	Riverside	Horiz. tan	85+300	385
Do	Holland Mfg. Co			S.	75	75	Anth	Backus				
Do	M. Pimes & Co	Woodwork	1906	S.	45	45	Anth	Otto				
Do	Slaysman & Co		1910	S.	30	30	Anth	Otto				
Do	Charles Williams Sanitary Works.		1908	S.	120	120	Anth	Otto				
Bel Air	Reckord Mfg. Co	Power flour mill.	1912	S.	50	50	Anth	Smith	B. M	Vert	50	50
Benevelo	Kline Bros	Flour mill	1909	S.	75	75	Anth	Smith	B. M	Vert	50	50
Berlin	Town of Berlin		1909		75	75	Anth	F. M	F. M	Vert	65	65
Cambridge	Cambridge Gas Co		1909	P.	125	125	Anth	West	West	Vert	100	100
Do	L. K. Warren	Mill	1908	S.	50	50	Anth	Smith	Jacobson	Horiz. tan	50	50
Clear Springs	Prather & Neimyer	Power flour mill.	1910	S.	35	35	Anth	Smith	B. M	Vert	35	35
Denton	Peninsular Light & Power Co.		1910	S.	150	150	Anth	S. W	S. W	Vert	150	150
Ellicott City	Patapsco Electric & Mfg. Co.	Electric light and power.	1911	S.	300	300	Anth	Smith	B. M	Vert	300	300
Do	do		1912	S.	200	400	Anth	Smith	(a)	(a)	(a)	(a)
Hagerstown	D. A. Stickell	Mill	1909	S.	130	130	Anth	Otto				
Hebron	Hebron Milling Co		1911	S.	70	70	Anth	Otto				
Hurlock	Hurlock Milling Co		1908	S.	75	75	Anth	Smith	Jacobson	Horiz. tan	75	75
New Windsor	New Windsor Electric Light & Water Co.	Electric light	1909	S.	50	50	Anth	Smith	B. M	Vert	50	50
Roland Park	Roland Park Co	Belted power	1909				Anth	Wood	West	Vert	75	75
Sykesville	W. H. D. Warfield & Co.		1909	S.	70	70	Anth	Otto				
Massachusetts:												
Ashley Falls	Ashley Falls Marble Co		1905	P.	250	250	Anth	West	West	3-cyl. vert	165	165
Billerica	E. E. Cole	Power	1909	S.	75	75	Anth	Smith	Pohl	Horiz	75	75
Boston	Boston Elevated R. R. Co.					1,500	Anth	Wood	Koerting	2-cyl		

Do	J. P. Eustus Mfg. Co.		1908	S. P.	100	100	Anth.	Wile	B. M.	Vert	55	110
Do	do	Factory drive.	1910	S.	100	100	Anth.	Wile	B. M.	Vert	55+125	180
Brightwood	Blair Mfg. Co.	Power	1909	S.	35	35	Anth.	Smith	Nash	Vert	35	35
Cambridge	Franklin Steel Works	Belted power	1907	S.	35	35	Anth.	Smith	Rathbun	Vert	35	35
Chelsea	Soldiers' Home		1908-9	S.	65	195	Anth.	S. W.	S. W.	Vert	65	195
Chicopee	Page, Storms Drop Forge Co.		1910		300	300	Anth.	West	Weber			
Do	do		1911		300	300	Anth.	West	West			
Hingham	Hingham waterworks		1906	N. b.	65	65	Anth.	Olds	Olds	1-cyl. horiz	65	65
Holbrook	C. A. C. Axe Co.		1907	S.	60	60	Anth.	Wile	B. M.	Vert	55	55
Lawrence	Lawrence Duck Co.		1905	S.	250	250	Anth.	L. P				
Manchester	City of Manchester		1909	S.	50(2), 75(2)	250	Anth.	Smith	Nash	Vert	50(2), 75(2)	250
Mansfield	Mansfield Cracker Co.		1910		100	100	Anth.	West	West	Vert	34	34
Mattapan	A. J. Wilkinson & Co.	Belted power	1906				Anth.	Wood	West	Vert	50	50
Middleboro	Middleboro Gas & Electric Co.		1907	P.	125(1) 175(1)	300	Anth.	West	West	3-cyl. vert	85+100+140	325
Do	Cash Coal Co.		1910		100	100	Anth.	West	West	Vert	95	95
Nantucket	Citizens' Gas, Electric & Power Co.		1905	P.	175	175	Anth.	West	West	Vert	85(2)	170
Newburyport	Hale Knight			S.	50	50	Anth.	Weber	Weber	1-cyl. horiz	50	50
New Bedford	C. S. Knowles	Power	1910	S.	25	25	Anth.	Smith	Elyria	Horiz	25	25
Do	New Bedford Gas & Light Co.	Power	1906	D. d.			Bit	L. P	West	Horiz	500	500
Do	New Bedford Industrial School.	Electric light and power.	1911	S.	50	50	Anth.	Smith	Elyria	Horiz	50	50
North Easton	W. H. Ames	Power	1904	S.	75	75	Anth.	Otto				
North Plymouth.	Plymouth Cordage Co.				500	500	Anth.	De la V	Koerting	4-cycle		
North Woburn	Merrimac Chemical Co.	Power			150	150	Coke	De la V	Koerting	4-cycle		
Shelburne Falls	Shelburne Falls Electric Light & Power Co.		1908	S.	125	125	Anth.	West	West	2-cyl	50+100	150
Shelton	Radcliffe Bros							West	West	2-cyl	57	57
Somerville	Boston Elevated R. R. Co.		1906	D. d.		1,500	Bit	L. P	Crossley	2-cyl	610	1,220
Southbridge	DuPaul-Young Optical Co.		1907	N. b.	90	90	Anth.	Olds	Olds	1-cyl. horiz	65	65
Westford	Westford waterworks		1907	N. b.	50	50	Anth.	Olds	Olds	1-cyl. horiz	50	50
West Springfield.	West Springfield waterworks.		1908	S.	75	75	Anth.	Smith	Olin	Horiz	75	75
Worcester	American Steel & Wire Co.		1905	D. d.	1,000	1,000	Bit	L. P	West	Horiz	800	800
Do	Norton Emery Wheel Co.		1906	D. d.	500	500	Bit	L. P	West	Tan	470	470
Do	Spencer Wire Co.		1909	S.	250	250	Anth.	West	West	Vert	35+180	215
Do	Wilson & Sinclair		1905	P.	50	50	Anth.	West	West	Vert	40	40

[a] Engine not yet installed.

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Michigan:												
Baraga	City of Baraga	Electric light and power.	1912	S.	150	150	Anth.	Smith	Nash	Vert.	100+35	135
Battle Creek	United States Register Co.	Power	1907	S.	25	25	Anth.	Smith	Columbus	Horiz.	25	25
Berrien Springs	J. B. Dumont	Power for mill.	1907	S.	25	25	Anth.	Smith	Columbus	Horiz.	25	25
Boyne City	Boyne Chemical Co.		{1908 1909}	S.	{90+ 150+ 150}	390	{Charcoal Braise}	S. W.	S. W.	Vert.	90+150+150	390
Caledonia	M. Wilson		1906	S.	45	45	Anth.	Otto				
Calumet	A. L. Carnahan			S.	40	40	Anth.	Weber	Weber	2-cyl. vert.	40	40
Detroit	Armstrong Woolen Mills	Power	1909	S.	35	35	Anth.	Smith	Foos	Horiz.	35	35
East Lake	R. G. Peters Salt & Laboratory Co.		1909		75	75	Anth.	F. M.	F. M.	Horiz.	50	50
Evart	Champion Tool and Handle Co.		1907	S.	45	45	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	45	45
Grand Rapids	Citizens Telephone Co.	Electric light and power.	1905	S.	21	21	Anth.	F. M.	F. M.	Horiz.	21	21
Do.	Grand Rapids Brass Co.	Light and power.	1905	S.	160	160	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	160	160
Do.	Grand Rapids Hydraulic Co.	Pumping	1909	S.	100	200	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	100	200
Do.	Heyman Co.		1907	N. b.	130	130	Anth.	Olds	Olds	1-cyl. horiz.	65	130
Do.	do.			S.			Anth.	Otto				
Houghton	Copper Concentrating Co.			S.		250	Anth.	Weber	Weber	2-cyl. vert.	250	250
Jackson	Michigan Central R. R.		1910		21	21	Anth.	F. M.	F. M.	Horiz.	21	21
Lansing	General Motors Co.		1908-9	N. b.	300	1,500	Anth.	Olds	Olds	1-cyl. horiz.	{300(4) 150(1)}	1,350
Saginaw	Furstenburg Bros.	Belt drive to mill.	1907	S.	50	50	Anth.	Smith	Columbus	Horiz.	50	50
Sandusky	F. A. Rickle	Flour mill	1907	S.	50	50	Anth.	F. M.	F. M.	Horiz.	50	50
South Haven	City of South Haven			S.	125	125	Anth.	Weber	Weber	3-cyl. vert.	125	125
Wayland	Wayland Light and Power Co.			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Zeeland	Ver Hage Milling Co.		1908	S.	50	50	Anth.	Smith	Columbus	Horiz.	50	50
Minnesota:												
Albany	Village of Albany		1909		50	50	Anth.	F. M.	F. M.	Vert.	43	43
Alexandria	Atwood Bros. & White Co.	Flour mill	1907	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Do.	Riverside Mfg. Co.	Woodworking machinery.	1907	S.	50	50	Anth.	F. M.	F. M.	Horiz.	45	45

Brainerd	Light, Heat & Power Co.	Electric light	1911	S.	150	450	Anth.	M. S. & M.	Muenzel	Tan. sing. act.	300+175	475
Browns Valley	Village of Browns Valley		1911	S.	125	125	Anth.	M. S. & M.		Sing. act. side crank.	115	115
Buffalo	City of Buffalo	Electric light and water.	1910	S.	125	125	Anth.	Smith	Nash	Vert.	125	125
Chisholm	Range Power Co.			S.		475	Anth.	Weber	Weber	3 & 4 cyl. vert.	300+175	475
Clarkfield	Clarkfield Roller Mills & Electric Light Co.		1909	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Cologne	Cologne Mill Co.	Driving flour mill.	1912	S.	65	65	Anth.	M. S. & M.	Muenzel	Sing. act.	65	65
Crookstown	Polk County Electric Co.	Power	1906	S.	35	35	Anth.	F. M.	F. M.	Horiz.	30	30
Dawson	Village of Dawson	Electric light	1907	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Deer River	W. A. Everton	Electric light	1909	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Evansville	Long, Atwood & White	Feed mill and elevator.	1906	S.	21	21	Anth.	F. M.	F. M.	Horiz.	21	21
Fairmont	City of Fairmont	Electric light	1907	S.	160	320	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80+160	240
Do.	do.	Electric plant.	1911	S.	150	300	Anth.	M. S. & M.	Muenzel	Tandem	375	375
Hibbing	Silliman, A. P.	Flour mill	1909	S.	75	75	Anth.	Smith	Foos	Vert.	75	75
McIntosh	McIntosh Roller Mill	Electric light and power.	1906	S.	65	65	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	65	65
Minneapolis	Minneapolis & St. Louis Ry. Co.	Railroad shops	1907	S.	140 90 90	320	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	140 80 65 30	315
Do.	Rowe Waterman Lumber Co.	Power	1906	S.	50	50	Anth.	F. M.	F. M.	Vert.	43	43
Do.	University of Minnesota	Electric light	1906	S.	60	60	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	60	60
New Ulm	Bingham Bros.	Grain cleaning	1907	S.	100	100	Anth.	F. M.	F. M.	Vert.	100	100
Renville	W. J. Ashley	Flour mill	1907	S.	55	55	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	55	55
Silver Lake	Silver Lake Mfg. Co.	Flour mill	1905	S.	100	100	Anth.	Smith	Foos	Vert.	100	100
Tyler	Village of Tyler	Electric light	1909	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	65	65
Missouri:												
Bonne Terre	St. Joe Lead Co.		1907-1909	D. d.	2,000	6,000	Bit.	L. P.	Snow	3 twin tan. 1 sing. tan.	800 100	2,500
Bonnots Mill	Meyer-Marfield Milling Co.	Milling	1908	S.	75	75	Anth.	F. M.	F. M.	Horiz.	50	50
Cape Girardeau	Harley Shoe Co.	Shoe - factory machinery.	1906	S.	21	21	Anth.	F. M.	F. M.	Horiz.	21	21
Crystal City	Pittsburgh Plate Glass Co.		1908-9	D. d.	4,500 1,500	6,000	Bit.	L. P.	Allis-Chalmers			
Do.	do.	Factory power	1910	D. d.	1,500	3,000	Bit.	L. P.	Allis-Chalmers.			
Festus	City of Festus	City lights	1905	S.	100	100	Anth.	F. M.	F. M.	Horiz.	70	70
Gilliam	Gilliam Electric Light Co.			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Kansas City	Gowie Electric Co.			S.	60	60	Anth.	Weber	Weber	3-cyl. vert.	60	60
Do.	Hudson Publishing Co.			S.	75	75	Anth.	Weber	Weber	2-cyl. vert.	75	75
Lathrop	H. L. Rogers			S.	125	125	Anth.	Weber	Weber	2-cyl. vert.	125	125
Linn Creek	Moulder Bros.			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Maitland	Maitland Electric Light & Power Co.	Electric light	1907	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Marceline	Marceline Electric Co.		1909		100	100	Anth.	F. M.	F. M.	Horiz.	85	85
Maryville	Maryville Electric Light & Power Co.		1908	S.	140	140	Anth.	Otto				

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horse-power (each unit).	Total producer horse-power.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horse-power (each engine).	Total engine horse-power
Missouri—Contd.												
Rivermines	Doe Run Lead Co.		1911		500	1,000	Bit.	West.	Snow			
Sarcoxie	Sarcoxie Electric Lighting Co.			S.	80	80	Anth.	Weber	Weber	3-cyl. vert.	80	80
Springfield	R. C. Stone			S.	35	35	Anth.	Weber	Weber	1-cyl. horiz	35	35
St. Louis	Hunkins-Willis Co.			S.		160	Anth.	Weber	Weber	2 & 3 cyl. vert.	60+100	160
Do	Peerless Box Co.		1909	S.	75	75	Anth.	F. M.	F. M.	Horiz.	50	50
Do	St. Anthony's Hospital.	Electric light and power.	1910	S.	50	50	Anth.	Smith	Rathbun	Vert.	50	50
Montana:												
Philipsburg	Bowen Bros.			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Do	Philipsburg Iron Works.	Power and electric light.	1910	S.	100	100	Anth.	Smith	Weber	Vert.	100	100
Nebraska:												
Albion	Albion Alfalfa Meal Mill.	Milling	1908	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65
Alma	City of Alma	Lights and waterworks.	1906	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65
Arapahoe	City of Arapahoe	Electric light and water.	1909	S.	100	100	Anth.	Smith	Buckeye	Horiz.	100	100
Beaver Crossing.	Beaver Crossing Electric Light Co.		1908	S.	40	40	Anth.	Otto				
Butte	E. E. Bushnell	Power	1907	S.	75	75	Anth.	F. M.	F. M.	Horiz.	65	65
Cambridge	Cambridge Electric Co.			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Crab Orchard.	Crab Orchard Electric Co.		1907	S.	45	45	Anth.	Otto				
Dodge	Village of Dodge		1906	S.	75	75	Anth.	Otto				
Hampton	Hampton Mill & Grain Co.	Flour mill	1906	S.	75	75	Anth.	F. M.	F. M.		65	65
Juniata	W. H. De Sanno & Son.			S.	40	40	Anth.	Weber	Weber	2-cyl. vert.	40	40
Lincoln	University of Nebraska.	Experimental.	1909	S.	50	50	Anth.	Smith				
McCook	McCook Electric Co.			S.	100	100	Anth.	Weber	Weber	3-cyl. vert.	100	100
Do	Updyke Grain Co.	Terminal elevator.	1905	S.	21	21	Anth.	F. M.	F. M.	Horiz.	21	21
Mitchell	Mitchell, A. M. & E. C., Co.		1909		100	100	Anth.	F. M.	F. M.	Vert.	100	100
Omaha	Bennett Co.	Lighting	1909	S.	200	200	Anth.	Smith	Buckeye	Horiz. tan.	100	100
Do	do	Electric light and elevators.	1908		150	150	Anth. or bit.	Smith	Buckeye	Horiz.	150	150
Pierce	Hemler & Cravens			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Ponca	Farmers' Mill & Elevator Co.	Flour mill	1908	S.	50	50	Anth.	Smith	Buckeye	Horiz. tan.	50	50
Randolph	City of Randolph	Electric light.	1906	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80

Stanton	City of Stanton	City lights and power.	1907	S.	100	100	Anth.	F. M.	F. M.	Vert.	100	100
Do.	F. L. Sanders	Flour mill	1907	S.	50	50	Anth.	F. M.	F. M.	Vert.	43	43
Wisner	Town of Wisner			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Nevada:												
Cherry Creek	Glasgow & West Express Co.		1908	S.	200	200	Anth.	F. M.	F. M.	Vert.	150	150
New Hampshire:												
Keene	Keene Gas & Electric Co.		1905-6	P.	250	500	Anth.	West.	West.	Vert.	125(2) 160(1)	410
Milford	Milford Electric Light Co		1905	S.	250	500	Anth.	L. P.				
New Jersey:												
Asbury Park	American Pipe Co.	Waterworks	1905	S.	50	50	Anth.	Otto				
Do.	East Jersey Coast Water Co.		1905	S.	50	50	Anth.	Otto				
Bayonne	Bayonne Castings Co.		1910		100	100	Anth.	F. M.	F. M.	Vert.	100	100
Do.	Southern Cotton Oil Co.	Power	1909	S.	100	100	Anth.	Smith	Rathbun	Vert.	100	100
Beverly	T. Burkhead	Worsted mills	1904	S.	30	30	Anth.	Otto				
Bronton	Jos. T. Ryerson & Son		1911		150	150		F. M.	F. M.	Vert.	150	150
Burlington	Thomas Devlin Mfg. Co.		1907	P.		350	Anth.	Wood	West.	Vert.	270	270
Camden	Armstrong Cork Co.			S.		300	Anth.	Wood				
Do.	do		1910	S.	300	300	Anth.	Smith	Allis-Chalmers	Horiz.	300	300
Do.	Martin J. Frand	Marble works	1904	S.	50	50	Anth.	Otto				
Do.	Taylor Bros.	Milling	1903	S.	120	120	Anth.	Otto				
Cape May	Sewage disposal plant		1909	S.	100	100	Anth.	Otto				
East Orange	General Service Heat & Power Co.			S.	75	75	Anth.	Backus				
Elizabeth	Wm. Finck Co.	Metal works	1905	S.	45	45	Anth.	Otto				
Florence	Florence Iron Works			P.		700	Anth.	Wood				
Garfield	Hammerschlag Mfg. Co.		1910- 1911		250	1,000	Anth.	West.	Koerting West.	Horiz.	575	575
Grenloch	Bate Mfg. Co.	Agricultural implements.	1904	S.	130	130	Anth.	Otto				
Guttenberg	American Cotton Oil Co.	Electric transmission.	1912	S.	250	750	Anth.	Smith	Allis-Chalmers	Horiz.	300	600
Haddonfield	Borough Water Works		1910	S.	100	200	Anth.	Otto				
Harrison	Harper Brick Co.		1905	S.	27	27	Anth.	Otto				
Do.	New Jersey Adamant Mfg. Co.			S.	50	50	Anth.	Backus				
Do.	T. Schriver & Co.	Foundry	1906	S.	95	95	Anth.	Otto				
Hightstown	E. C. Norton			S.	50	50	Anth.	Backus				
Hoboken	Stevens Institute	Experimental	1908	S.	30	30	Anth.	Otto				
Irvington	N. Drake			S.	50	50		Backus				
Jersey City	Erie Railroad			P.		400	Anth.	Wood	Otto & West.			
Do.	L. O. Koven & Bro.	Fuel gas and power.	1912	D. d.	500	500	Bit.	L. P.				250
Do.	Charles Mundt & Sons		1912	S.	100	100	Anth.	Otto				
Do.	Standard Motor Construction Co.	Shops	1907	D. d.	150	300	Bit.	L. P.[a]	Standard	6-cyl. vert.	300	300
Do.	Standard Watch Co.		1907		200	200	Anth.	Harvey	West.	3-cyl. vert.	130+30	160
Do.	Thomas Wright Co.				30	30	Anth.	Backus				

[a] Marine engine.

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
New Jersey—Con.												
Longport	Municipal Lighting Co.		1910	S.		275	Anth.	Wood	Foos			
Morristown	Arrowsmith Mining Co.		1908	S.	100	100	Anth.		B. M.	Vert.	45	45
Netcong	Willsbrook Electric Light Co.		1908	S.	75	75	Anth.	Smith	Nash	Vert.	75	75
Newark	Allsopp Bros.			S.	40	40	Anth.	Backus				
Do.	Atha Tool Co.		1904	D. d.	1,000	1,000	Bit.	L. P.	West.	Vert.	165(1) 140(3)	585
Do.	Herpers Bros.			S.	60	60	Anth.	Backus				
Do.	Hooter Cocoa & Chocolate Co.		1910		150	150	Anth.	F. M.	F. M.	Vert.	150	150
Do.	Newark Spring Mattress Co.			S.	50	50	Anth.	Backus				
Do.	John F. Schrink & Sons.			S.	40	40	Anth.	Backus				
Do.	Strobel & Crane		1907		100	100	Anth.	Harvey	West.	3-cyl. vert.	85	85
New Durham	F. J. Pels & Co.			S.	100	100	Anth.	Backus				
New Egypt	M. E. Lamb		1907	S.	60	60	Anth.	Wile	B. M.	Vert.	45	45
Do.	New Egypt Light & Power Co.		1907	S.	60	60	Anth.	Wile	B. M.	2-cyl. vert.	45	45
Newton	Newton Gas & Electric Co.	Town lighting.	1905	S.	300	300	Anth.		Crossley	2-cyl.	105+200	305
Do.	do.	Town lighting.	1911	D. d.	250	250	Bit.	L. P.	P. & M. M.	Horiz.		
Ocean City	Consumers' Ice & Coal Co.		1910	S.	150	150	Anth.	Otto				
Perth Amboy	Standard Underground Cable Co.		1909-1910		250	1,000	Anth.	West.	West.	Horiz.	730	730
Plainfield	Ransome Concrete Machine Co.		1907	S.	60	60	Anth.	Wile	Alberger	Horiz.	60	60
Do.	Rushmore Dynamo Works.		1908	S.	200	200	Anth.	Wile	Koerting	Horiz.	125	125
Do.	do.		1909		200	200	Anth.	Harvey	Nash & Koerting.		130+100	230
Do.	do.						Anth.	De La V.	Koerting	4-cycle	100+125	225
South River	Borough of South River.	Waterworks.	1911	S.	125	250	Anth.	Smith	Nash	Vert.	125	250
Wildwood	Wildwood Water Co.		1911	S.	50	100	Anth.	Otto				
New Mexico:												
Artesia	O. S. Coates			S.	60	60	Anth.	Weber	Weber	3-cyl. vert.	60	60
Fort Sumner	Fort Sumner Land & Drainage Co.		1909		75	75	Anth.	F. M.	F. M.	Vert.	65	65
Portales	Portales Irrigation Co.		1910		500	1,500	Bit.	West.	West.	Horiz.	750	1,500
Do.	Town of Portales.		1910		150	300	Anth.	F. M.	F. M.	Vert.	150	300
Rodeo	Hagan Mercantile Co.			S.	100	100	Anth.	Weber	Weber	2-cyl. vert.	100	100

Roswell	Roswell Gas & Electric Co.		1911		250	1,500	Bit.	West.	West.	2 horiz., 1 vert.	715+300+ 110	1,125
Do.	Roswell Wool & Hide Co.	Power	1908	S.	100	100	Anth.	Smith.	Buckeye.	Horiz.	100	100
New York:												
Alsen	Alpha Portland Cement Co.		1910	P.		1,800	Anth.	Wood.	A. C.			
Attica	Westinghouse Machine Co.		1905-1906	P.	250	500	Anth.	West.	West.	Vert.	115(1), 125(2)	365
Bath	Bath Waterworks		1908	S.	35	35	Anth.	Smith.	Foos.	Horiz.	35	35
Bemis Point	A. W. Rappole & Son	Electric light and water plant.	1907	S.	75	75	Anth.	Smith.	Otto.	Horiz.	25+50	75
Brooklyn	Adriance Machine Co.			S.	150	150	Anth.	Wile.	B. M.	2-cyl. vert.	65	130
Do.	Cameron Machine Co.	Electric generator.	1907	S.	50	50	Anth.	F. M.	F. M.	Horiz.	50	50
Do.	Mergenthaler Linotype Co.		1912	S.	300	300	Anth.	Smith.	Rathbun.	Vert.	300	300
Do.	National Meter Co.	Electric transmission.	1909	S.	300	300	Anth. or bit.	Smith.	Nash.	Vert.	100+200	300
Do.	do.	Testing	1911	S.	300	300	Anth.	Smith.				
Do.	Nonmagnetic survey yacht *Carnegie*.		1909	S.	150	150	Anth.	L. P.[a]	Craig.	4-cyl.	150	150
Do.	Phoenix Tube Co.	Electric transmission.	1910	S.	300	300	Anth.	Smith.	Nash.	Vert.	300	300
Do.	J. W. Wallace Co.		1908	S.	100	100	Anth.		B. M.	4-cyl. vert.	65	130
Do.	Weinlander & Jackson	Belted power	1911	S.	75	75	Anth.	Smith.	Nash.	Vert.	75	75
Buchanan	Standard Oil Co.	Factory power	1909	D. d.	250	500	Bit.	L. P.	Riverside.			
Carmel	Ellsworth Fowler	Belted power	1906				Anth.	Wood.	West.	Vert.	35	35
Catskill	Catskill Cement Co.		1909		200	200	Anth.	Harvey	Koerting.	4-cycle.	130	130
Cattaraugus	H. W. True		1908	S.	40	40	Anth.	Otto.				
Cohoes	City of Cohoes		1910		125	250	Anth.	West.	West.	Vert.	125	250
College Point	Automatic Press Co.	Electric transmission.	1910	S.	200	200	Anth.	Smith.	Nash.	Vert.	135	135
Cooperstown	Arthur H. Crist Co.	Electric lights and power.	1909	S.	75	75	Anth.	Smith.	Alberger.	Horiz.	75	75
Cortlandt	Cortlandt Carriage Goods Co.	Electric transmission.	1910	S.	300	300	Anth.	Smith.	Buckeye.	Vert.	385	385
Do.	Wickwire Bros.		1911	P.		1,350	Anth. or bit.	Wood.	Mesta.		500	1,000
Depew	Gould Coupler Co.	D. C. generators.	1903	D. d.		1,000	Bit.	L. P.	West.	3-cyl. vert.	235	705
Elmira	Cycle Hatcher Co.		1910	S.		50	Anth.	Syracuse.	Pohl.	1-cyl. horiz.	50	50
Flushing, L. I.	Heine Franck Sohne & Co.		1908	S.	200	200	Anth.	Otto.				
Do.	do.		1910	S.	200	400	Anth.	Otto.				
Harriman	Harriman Industrial Co.		1910		350	1,050	Bit.	West.	West.	Vert. & horiz.	50(2), 340(3)	1,120
Hilburn	Rockland Electric Co.		1903	D. d.	2,000	2,000	Bit.	L. P.	West.	Vert. & horiz.	50+125+ 3×400	1,375
Do.	do.		1906	D. d.	1,000	1,000	Bit.	L. P.	West.	Horiz.	470	940
Islip, L. I.	Long Island Lighting Co.		1911		100	100	Anth.	West.	West.	Vert.	60+100	160
Ithaca	Cornell University		1909	S.	65	65	Bit.	Amsler.				

[a] Marine engine.

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
New York—Contd.												
Ithica	Cornell University		1911		32	32	Anth.	West	West	Vert	32	32
Jamaica, L. I.	Clayton, B. R.			S.	50	50	Anth.	Backus				
Do.	Jamaica Paragon Plaster Co.			S.	50	50	Anth.	Backus				
Lake George	H. C. Knablanch		1910	S.	50	50	Anth.	F. M	F. M	Horiz	35	35
Mamaroneck	A. C. Bostwick	Waterworks	1911	S.	75	75	Anth.	Smith	Nash	Vert	75	75
Marcellus	Crown Mills	Electric transmission.	1910	S.	250	250	Anth.	Smith	Alberger	Horiz	250	250
Morristown	Arrowsmith Mfg. Co.	Factory drive	1908	S.	100	100	Anth.	Wile	B. M	2-cyl. vert	45	45
Do.	W. H. Comstock Co.	Grinding drugs	1906	S.	20	20	Anth.	F. M	F. M	Horiz	17	17
Do.	do.		1910	S.	75	75	Anth.	F. M	F. M	Horiz	50	50
Mount Vernon.	Max Ams Machine Co.			S.	75+200	275	Anth.	De La V	Koerting	4-cycle		175
Do.	Max Ams Machine Co. (second order).			S.			Anth.	De La V	Koerting	4-cycle		100
New York City.	Acme Electric Garage	Charging batteries.	1911	S.	200	200	Anth.	Wood	B. M	4-cyl. vert	75	150
Do.	De La Vergne Machine Co.			S.			Anth.	De La V	Koerting	4-cycle		
Do.	Hawley & Hoopes	D. C. generator	1905	S.		100	Anth.	Wood	West	Vert	85	85
Do.	George F. Heinrichs		1910-1911	S.	135	270	Anth.	S. W	S. W	Vert	135	270
Do.	C. E. Hertlein		1907	S.	125	125	Anth.	Wile	Jacobson	Horiz	120	120
Do.	do.		1909	S.	160	160	Anth.	Wile	J'c'bs'n & Wbr.	Horiz. and vert.	120+60	180
Do.	Ludwig & Co.					100	Anth.	De La V	Koerting	4-cycle		100
Do.	McCabe Hanger Mfg. Co.		1907	S.	75	75	Anth.	Otto				
Do.	Manhattan Screw & Stamping Works.		1910	S.	150	150	Anth.	Otto				
Do.	Motor boat Marenging		1909	S.	30	30	Anth.	L. P.[a]	Trescott	4-cyl	30	30
Do.	Pirika Chocolate Co.	Belted power	1907	S.	50	50	Anth.	Smith	Nash	Vert	50	50
Do.	Starr Engravers' Supply Co.	Power	1906	S.	100	100	Anth.	F. M	F. M	Vert	100	100
Do.	Swift & Co.	Electric lighting and refrigerating.	1907	S.	150+200	350	Anth.	Smith	Rathbun	Vert	100	400
Do.	do.		1910	S.	250	250	Anth.	Smith				
Do.	J. W. Wallace Co.		1908	S.	150	150	Anth.	Wile	B. M	Vert	65	130
Norwich	Clark Conroy Co.	Power	1907	S.	50	50	Anth.	Smith	Foos	Voriz	50	50
Oneida	Oneida Community		1909	S.	85	85	Anth.	S. W	S. W	Vert	85	85
Otselic	B. F. Gladding & Co.	Power	1910	S.	75	75	Anth.	Smith	Rathbun	Vert	75	75
Poughkeepsie	Municipal pumping plant.			S.		50	Anth.	Wood				

Redwood	Holmes Bros		1909	S.	75	75	Anth	F. M	F. M	Horiz	50	50
Richmond Hill	John Donaldson			S.	100	100	Anth	Backus				
Rochester	Armstrong Milling Co		1911	S.		150	Anth	Syracuse	Foos	3-cyl. vert	100	100
Do	Rochester Lead Works		1908	S.	60	60	Anth	Wile	B. M	Vert	65	65
Do	do		1911	S.		100	Anth	Syracuse	B. M	2-cyl. vert	75	75
Do	do		1911	S.			Anth	Syracuse	Pohl	1-cyl. horiz	50	50
Do	Wilmot Castle Co	Power	1907	S.	35	35	Anth	Smith	Rathbun	Vert	35	35
Rome	J. Karlen	Refrigerating plant.	1912	S.	25	25	Anth	Syracuse	Pohl	1-cyl	25	25
Do	Rome Electric Co		1910	S.	80	80	Anth	F. M	F. M	Vert	80	80
Roslyn	Town of Roslyn	Waterworks	1911	S.	50	100	Anth	Smith	Nash	Vert	50	100
Shelter Island	F. M. Smith		1911	S.	50	50	Anth	Otto				
Silver Springs	Municipal lighting plant		1911	S.		100	Anth	Syracuse	Nash	2-cyl. vert	75	75
Smiths Landing	Catskills Cement Co						Anth	De La V	Koerting	4-cycle		175
South Dayton	J. D. Fuller & Co	Power for cannery.	1907	S.	50	50	Anth	Smith	Alberger	Horiz	50	50
Syracuse	Humphrey Gas Pump Co.		1911	S.	15	15	Anth	Syracuse	Humphrey	Pump		
Do	Syracuse Milling Co	Flour mill	1909	S.	150	150	Anth	Smith	Alberger	Horiz	150	150
Troy	Rensselaer Polytechnic Institute.	Experimental	1908	S.	30	30	Anth	Otto				
Vernon	J. J. Bartholomew & Son		1911	S.	60	60	Anth	Syracuse	Pohl	1-cyl	60	60
Do	Geo. D. Pohl Mfg. Co	Power	1905	S.	25	25	Anth	Smith	Advance	Horiz	25	25
Do	do	Engine testing	1912	S.	100	100	Anth	Syracuse	Pohl			
Watertown	New York Air Brake Co		1907	S.	250	250	Anth	L. P	Snow	Twin tan	250	250
Waverly	Waverly Sayre Co	Feed mill	1906	S.	100	100	Anth	F. M	F. M		100	100
Westbury, L. I	Westbury Water Board		1912	S.	40	80	Anth	F. M	F. M	Vert	40	80
Whitestone, L. I.	Automatic Fire Protection Co.	Electric light and power.	1908	S.	25	25	Anth	Smith	Nash	Vert	28	28
Do	National Meter Co	Power and light.	1908	S.	28	28	Anth	Smith	Nash	Vert	28	28
Wilson	Conant Bryan Co	Electric light	1910	S.	100	100	Anth	Smith	Alberger	Horiz	100	100
North Carolina:												
Anderson	H. C. Townsend	Cotton mill	1906	S.	250	250	Anth	Smith	Otto	Horiz	250	250
Charlotte	Charlotte Const. Co		1908	D. d.	2,000	2,000	Bit	L. P	Snow	4-cyl. dbl. act	750	1,500
Nashville	N. C. Warren	Cotton mill	1906	S.	50	50	Anth	Smith	Foos	Horiz	50	50
Salisbury	J. D. Grimes			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Smithfield	Neuse Mfg. Co			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Thomasville	M. E. Bishop & Son			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
North Dakota:												
Cooperstown	Platt Electric Co			S.	100	100	Anth	Weber	Weber	2-cyl. vert	100	100
Do	do	Electric light	1905	S.	80	80	Anth	M. S. & M	Muenzel	Horiz	80	80
Devils Lake	Devils Lake Imp. Co		1908	S.	100	100	Anth	F. M	F. M	Vert	100	100
Jamestown	Russell-Miller Milling Co	Flour mill	1905	S.	80	80	Anth	M. S. & M	Muenzel	Horiz	80	80
Monango	W. A. Caldwell	Power	1905	S.	20	20	Anth	F. M	F. M	Horiz	20	20
Oakes	Home Hotel	Electric light	1907	S.	20	20	Anth	F. M	F. M	Horiz	17	17
Rugby	Rugby Milling Co	Flour mill	1909	S.	80	80	Anth	M. S. & M	Muenzel	Horiz	80	80
University	University of North Dakota.	Experimental	1909	S.	50	50	Anth	Smith	Alberger	Horiz	50	50
Valley City	E. A. Glynn	Electric light	1905	S.	15	15	Anth	Otto				

[a] Marine engine.

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Ohio:												
Attica	Cameron Car Co.	Power	1910	S.	100	100	Anth.	Smith	Hallet	Horiz	100	100
Avery	Hoover Mfg. Co.		1910		150	150	Bit.	West	West	Vert	60	120
Barberton	O. C. Barber		1910	S.	75+100	175	Anth.	F. M.	F. M.	Vert	50	150
Bedford	Bedford Electric Light & Power Co.		1910	S.	100	100	Anth.	Smith	Alberger	Horiz	100	100
Cincinnati	M. A. Hunt & Co.			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Do.	University of Cincinnati.	Experimantal.	1909	S.	35	35	Anth.	F. M.	F. M.	Horiz	25	25
Cleveland	Bruce Macbeth Engine Co.	Power and testing.	1910	S.	200	200	Anth. or bit.	Smith	B. M.	Vert	125	125
Columbus	Ohio State University	Experimental.	1910	S.	50	50	Bit.	Smith	Buckeye	Horiz	50	50
Delta	Helvetia Milk Condensing Co.		1908	S.	100	100	Anth.	F. M.	F. M.	Vert	100	100
Elyria	Elyria Gas Power Co.	Electric transmission and testing.	1909	S.	25+75	100	Anth.	Smith	Elyria	Horiz		
Do.	Garford Mfg. Co.		1908		750	750	Bit.	Harvey	Alberger		100	500
Hamilton	Krauth & Nenninghofen.		1907	N. b.	115	115	Anth.	Olds	Olds	1-cyl. horiz.	75	75
Hudson	Town of Hudson	Electric lighting.	1910	S.	175	175	Bit.	Smith	B. M.	Vert	175	175
Kinsman	Kinsman Electric Co.	Electric lighting.	1905	S.	35	35	Anth.					
Lexington	Lexington electric-light plant.		1902	S.	35	35	Anth.	Smith		Horiz	60	60
Do.	Smith Gas Power Co.	Power and lighting.	1905	S.	35	35	Bit.	Smith	Rathbun	Vert	60	60
Do.	do.	Electric transmission and heating.	1910	S.	100	100	Bit.	Smith	Rathbun	Vert	60	60
Lucasville	Purdy Bros.	Belt drive to mill.	1908	S.	50	50	Anth.	Smith	Jacobson	Horiz	50	50
Madison	A. N. Benjamin	Flour mill	1911	S.	60	60	Anth.	Traverse	B. M.	Vert	45	45
Marysville	Standard Stamping Co.	Belt drive	1907	S.	75	75	Anth.	Smith	Rathbun	Vert	60	60
Medina	Medina Granite & Marble Co.		1907	S.	25	25	Anth.	Smith	B. M.	Vert	25	25
Do.	Town of Medina	Waterworks	1908	S.	25	25	Anth.	Smith	B. M.	Vert	25	25
Do.	do.	Waterworks	1908	S.	25	25	Anth.	Smith	Columbus	Horiz	25	25
Niles	Souder Lumber Co.		1905	S.	35	35	Anth.	Smith	Walrath	Vert	35	35
Port William	W. O. Beam		1910	S.	75	75	Anth.	F. M.	F. M.	Horiz	50	50
Ravenna	D. R. Hanna		1908	S.	35	35	Anth.	F. M.	F. M.	Horiz	25	25
Rushsylvania	White Oak Milling Co.	Electric light and power.	1907	S.	50	50	Anth.	Smith	Weber	Vert	60	60

Springfield	Foos Gas Engine Co.	Engine testing	1908	S.	100	100	Bit.	Smith	Foos			
Toledo	Bureau of Filtration		1909–1911	S.		1,400	Bit.	Wood	Rathbun			
Do.	Rathbun-Jones Engine Co.	Testing	1908	S.	200	200	Bit.	Smith	Rathbun			
Do.	Vacuum and Com. Co.	Light and power.	1906	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65
Wakeman	F. A. Denman		1910		75	75	Anth.	F. M	F. M.	Horiz.	30	60
Warren	Day Ward Co.		1907	S.	55	55	Anth.		B. M.	2-cyl. vert.	55	55
Do.	Hydro-Electric & Gas Co		1909	N. b.			Anth.	Olds	Olds	1-cyl. horiz.	300	300
Wellington	J. H. Shelley	Flour mill	1911	S.	100	100	Anth.	Smith	Elyria	Horiz.	50	50
Wickliffe	J. W. Corrigan		1911	S.	50	50	Anth.	F. M.	F. M.	Vert.	50	50
Oklahoma:												
Antlers	Antlers Light & Power Co.		1909	S.	100	100	Anth.	F. M	F. M.	Vert.	65	65
Bickford	Roman Nose Gypsum Co		1908	D. d.	250	250	Bit.	L. P.	Weber	3-cyl. vert	250	250
Fairview	Fairview Milling Co.			S.	60	60	Anth.	Weber	Weber	2-cyl. vert.	60	60
Do.	Town of Fairview			S.		150	Anth.	Weber	Weber	2-cyl. vert.	75	150
Fort Gibson	Boudinot & Pyle	Electric lighting.	1908	S.	50	50	Lig. & anth.	F. M.	F. M.	Horiz.	50	50
Okmulgee	Town of Okmulgee			S.	60	60	Anth.	Weber	Weber	2-cyl vert.	60	60
Oregon:												
Coyote	Blalock Island Irrigation Co.			S.	100	100	Anth.	Weber	Weber	3-cyl. vert.	100	100
Irrigon	Drumheller Development Co.			S.	100	100	Anth.	Weber	Weber	3-cyl. vert.	100	100
Pennsylvania:												
Akron	H. C. Bittner		1912	S.	150	150	Anth.	F. M.	F. M.	Vert.	150	150
Allegheny	W. N. Richey			P.	35	35	Anth.	Amsler				
Allentown	Roemig & Bro.	Mill	1907	S.	50	50	Anth.	Smith	Columbus	Horiz.	50	50
Bangor	Pahoquarry Copper Co.			S.	200	200	Anth.	Weber	Weber	3-cyl. vert.	200	200
Bellville	J. D. Greybill & Sons	Flour mill	1907	S.	75	75	Anth.	Smith	Jacobson	Vert.	75	75
Cornwells	Enterprise Mfg. Co.		1910	P.		900	Anth.	Wood	Rathbun			
Corry	Clark Titanite Explosive Co.		1909	S.	150	150	Anth.	Otto				
Dushore	Dushore Light, Heat & Power Co.	City lights	1906	S.	100	100	Anth.	F. M.	F. M.	Vert.	100	100
East York	American Caramel Co.		1911	S.	75	75	Anth.	F. M.	F. M.	Vert.	75	75
Eddystone	Penn Iron Works Co.		1907	S.	75	75	Anth.	Otto				
Lebanon	Swatara Power Co.		1910		175	175	Anth.	West.	West.	Vert.	140	140
Millersburg	Millersburg Hardware C.		1909	S.	45	45	Anth.	F. M.	F. M.	Horiz.	45	45
North Water Gap	Rossiter Realty Co.		1911		150	150	Anth.	West.	West.	Vert.	40	80
Oil City	Riverside Engine Co.			S.	250	250		Amsler				
Pencoyd	American Bridge Co.		1907	S.		400	Anth.	L. P.	Snow	Horiz. twin	400	400
Philadelphia	American Snuff Co.		1906	P.	85	85	Anth.	West.				
Do.	Barr Manufacturing Co.	Textile works	1904	S.	27	27	Anth.					
Do.	Hugo Bilgram		1903	S.	45	45	Anth.	Otto				
Do.	Bilgram Machine Co.		1911	S.	150	150	Anth.	Otto				
Do.	A. A. Bornot & Bro.			P.		250	Anth.	Wood				
Do.	Bower Chemical Mfg. Co.		1907	P.	175	175	Anth.	West.	West.	3-cyl. vert.	100	300
Do.	George S. Cox & Bro.		1907	S.	120	120	Anth.	Otto				
Do.	Robt. Creeland's Sons		1904	S.	75	75	Anth.	Otto				

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Pennsylvania—Con.												
Philadelphia	P. Deisler & Bros		1906	S.	15	15	Anth.	Otto				
Do	Eagle Ice & Coal Co		1912	S.	150	150	Anth.	Otto				
Do	Finnessy & Kobler	Electric light and power.	1907	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65
Do	Fowler Waist Co		1903	S.	80	80	Anth.	Otto				
Do	F. T. Gabylewitz			S.	50	50	Anth.	Backus				
Do	Geo. F. Laaher		1910	S.	260	520	Anth.	S. W.	S. W.	Tan.	260	520
Do	Lanston Monotype Machine Co.		1905	S.	120	120	Anth.	Otto				
Do	Leeds & Northrup		1905	S.	27	27	Anth.	Otto				
Do	Keystone Lubricating Co		1910	S.	70	70	Anth.	Otto				
Do	E. P. Moitz		1907	S.	45	45	Anth.	Otto				
Do	National Cutlery Co		1904	S.	75	75	Anth.	Otto				
Do	Otto Gas Engine Works		1887	S.	250	250	Anth.	Otto				
Do	Philadelphia Hydro-Electric Co.	60-cycle	1910				Anth.	Wood	West.	Vert.	270	270
Do	Philadelphia Rapid Transit Co.	A. C. generator	1911				Anth.	Wood	West.	Horiz.	825	825
Do	Philadelphia Stove & Iron Foundry.		1904	S.	45	45	Anth.	Otto				
Do	Pooley Furniture Co		1906	S.	75	75	Anth.	Otto				
Do	P. J. Ritter Conserve Co.		1905	S.	27	27	Anth.	Otto				
Do	Schutte & Koerting Co.	Power				125	Anth.	De la V	Koerting	4-cycle		125
Do	W. Shoe			S.	50	50	Anth.	Backus				
Do	Smith & Son			S.	50	50	Anth.	Backus				
Do	John B. Stetson & Co		1910	S.		550	Anth.	Wood				
Do	J. S. Thorne Co		1906	S.	120	120	Anth.	Otto				
Do	H. P. Underwood & Co.		1904	S.	45	45	Anth.	Otto				
Do	do		1911	S.	70	70	Anth.	Otto				
Do	University of Pennsylvania.	Experimental.	1907	S.	27	27	Anth.	Otto				
Do	Walker Mfg. Co		1909	S.	50	50	Anth.	Otto				
Do	D. Warner & Co		1907	S.	27	27	Anth.	Otto				
Pittsburgh	Carnegie Technical School.	Experimental.	1911	S.	75	75	Anth.	Amsler				
Pottstown	Chadwick Engineering Works.		1906	N. b.	65	65	Anth.	Olds	Olds	1-cyl. horiz.	65	65
Do	Stanley G. Flagg & Co		1909 1911	P.		550	Anth.	Wood	West.			
Reading	Curtis & Jones						Anth.	De la V	Koerting	4-cycle		150

Do.	Pennsylvania Hardware Co.		1906	S. P.	300	300	Anth.	Wile	Koerting		150	150
Do.	Reading Crane & Hoist Works.	Power	1908	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65
Do.	Reading Iron Works Co.		1910	P.	300	600	Bit.	Amsler			250	250
Do.	Reading Water Board		1910	S.	75	150	Anth.	F. M.	F. M.	Horiz.	50	100
Reedville	Spanogle-Yeager Milling Co.	Flour mill	1910	S.	75	75	Anth.	Smith	B. M.	Vert.	60	60
South Montrose	Percy Ballentine Estate.		1911	S.	50	50	Anth.	Smith	Nash	Vert.	50	50
State College	Nittany Light, Heat & Power Co.	Electric lighting.	1905	S.	75	75	Anth.	F. M.	F. M.	Vert.	70	70
Do.	do.	A. C. generator	1907				Anth.	Wood	West.	Vert.	270	270
Stowe	Stanley G. Flagg & Co.	D. C. generator	1909				Anth.	Wood	West.	Horiz.	300	300
Do.	do.	do.	1911				Anth.	Wood	West.	Horiz.	300	300
Stoyestown	Stoyestown Light, Heat & Power Co.	Light and power.	1908	S.	50	50	Anth.	F. M.	F. M.	Vert.	45	45
Tamaqua	L. G. Edwards Co.		1910	S.	75	75	Anth.	F. M.	F. M.	Horiz.	50	50
Taylor	Victoria Silk Co.	Mill power	1912	S.	150	150	Anth.	P. & M.	Ingeco	3-cyl. vert.		150
Torresdale	Pennypack Creek Pumping Station.		1911		175	175	Anth.	West.	West.	Vert.	30+50+70	150
York	Dentists' Supply Co.		1908	S. P.	200	200	Anth.	Wile	B. M.	Vert.	80	80
Rhode Island:												
Newport	New York Transportation Co.		1902				Anth.	Wood	West.	Vert.	25+85+125	235
Pawtucket	Howard & Bullough	Manufacturing plant.	1907	S.	200	200	Anth.	Smith	West.	Vert.	200	200
Do.	do.	Electric transmission.	1911	S.	250	250	Anth.	Smith	West.	Vert.	200	200
Providence	Brown & Sharp	Power		S.	75	75	Anth.	De la V	Koerting	4-cycle	75	75
Saylesville	Sayles Bleacheries	D. C. generator	1900 1906	D. d.	1,000	2,000	Bit.	L. P.	Crossley & West		250+500	750
Woonsocket	Woonsocket Machine Press Co.		1905	P.	100	100	Anth.	Harvey	1 West 1 Stockport	Vert. Horiz.	50 50	100
South Carolina:												
Columbia	Swift & Co.	Cotton-oil mill	1911	S.	250	250	Bit.	Akerlund	Amer. Crossley.	2-cyl. horiz.	250	250
Do.	Glencoe Cotton Mills	Electric transmission.	1912	S.	200	200	Bit.	Smith	Rathbun	Vert.	200	200
Dillon	Southern Cotton Oil Co.		1910		200	200	Bit.	West.	West.	Vert.	190	190
Florence	Florence Light & Power Co.	Belted power	1904				Anth.	Wood	West.	Vert.	125	125
Greenwood	Southern Cotton Oil Co.		1910		200	200	Bit.	West.	West.	Vert.	140	140
South Dakota:												
Aberdeen	Aberdeen Light & Power Co.	Electric light and power.	1907 1908	S.	150	600	Anth.	M. S. & M.	Muenzel	Horiz.	280+300	580
Do.	do.	Electric light and power.	1910 1911	S.	150	600	Anth.	M. S. & M.	Muenzel	Tan. d'ble act.	400	800
Do.	I. Appek Co.	Electric light	1905	S.	21	21	Anth.	F. M.	F. M.	Horiz.	21	21
Armour	Armour Roller Mills	Flour mill	1905	S.	75	75	Anth.	Otto				
Do.	Dakota Gas, Electric & Power Co.	Electric light	1907	S.	100	100	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	100	100
Carthage	W. W. & H. B. Potter	Electric light	1909	S.	65	65	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	65	65
Fairfax	Fairfax Milling Co.	Flour mill	1907	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horse power
S. Dak.—Contd.												
Gary	Citizens' Electric Co.	Electric light	1907	S.	35	35	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	35	35
Geddes	Geddes Power Co.	City light	1907	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65
Gettysburg	Gettysburg Milling Co.	Power	1908	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65
Huron	Huron Light & Power Co.	Electric light	1909	S.	150	300	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	100+150	250
Do.	do.	Electric light	1910 1911				Anth.		Muenzel	Horiz. sing. act.	150+100	250
Ipswich	Ipswich Electric Light & Power Co.		1909	S.	65	65	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	65	65
Lake Andes	Dakota Gas, Electric Light & Power Co.		1909	S.	30+35	65	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	30+35	65
Madison	City of Madison	Electric light	1909	S.	150	300	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	90+250	340
Menno	B. M. Kost & Co.	Power	1912	S.	75	75	Anth.	Smith	I. H. C.	Vert.	35	35
Millbank	O Clauson	Electric light	1909	S.	100	100	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	90	90
Do.	do.	Electric light	1911	S.	100	100	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Pierre	City of Pierre		1911		200	200	Anth.	West.	West.	Vert.	175	175
Platte	Dakota Gas, Electric Light & Power Co.		1907	S.	80	80	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	80	80
Do.	Charles Mix Milling Co.		1905	S.	120	120	Anth.	Otto				
Scotland	Dakota Gas, Electric Light & Power Co.		1909	S.	100	100	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	65	65
Sioux Falls	John Morrell & Co.	Refrigeration	1911	S.	200	200	Anth.	Smith	Rathbun	Vert.	200	200
Sisseton	Sisseton Mill & Light Co.	Flour mill	1909	S.	125	125	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	125	125
Tyndall	City of Tyndall	Electric light	1910	S.	100	200	Anth.	M. S. & M.	Muenzel	Horiz. sing. act.	65+90	155
Utica	Hutterische Brüder Demeinde.		1909	S.	50	50	Anth.	Otto				
Wagner	Dakota Gas, Electric Light & Power Co.	Electric light	1906 1909	S.	45+80	125	Anth.	M. S. & M.	Muensel	Horiz. sing. act.	45+80	125
Wessington Springs.	Gerauld Milling Co.	Flour mill	1909	S.	75	75	Anth.	Smith	Foos	Vert.	75	75
Do.	Wessington Springs Electric Light Co.	Electric light	1907	S.	75	75	Anth.	F. M.	F. M.	Vert.	65	65
Do.	do.	Electric light	1912	S.	100	100	Anth.	Smith	F. M.	Vert.	50	50
Wilmot	Village of Wilmot	Electric light and pumping.	1905	S.	50	50	Anth.	F. M.	F. M.	Vert.	43	43
Tennessee:												
Humboldt	Humboldt Marble Works.		1907	S.	75	75	Anth.	F. M.	F. M.	Horiz.	50	50
Memphis	Memphis Fibre Plaster Co.		1906	S.	75	75	Anth.	F. M.	F. M.	Horiz.	50	50

Texas:											
Amarillo	Amarillo Water, Light & Power Co.		1910		350	350	Bit.	West.	West.	Horiz.	225	225
Do.	do		1911		350	350	Bit.	West.	West.	Horiz.	225	225
Blooming Grove.	Home Light, Water & Ice Co.	Electric light.	1908	S.	60	60	Lig.	Smith.	Rathbun.	Vert.	60	60
Brownwood.	City of Brownwood	Waterworks.	1909	S.	100	100	Lig.	Smith.	Foos.	Vert.	100	100
Callahen.	Nueces River Irrigation Co.		1910	S.		200	Lig.	Wood.	Foos.			
Canadian.	Canadian Water, Light & Power Co.		1910		100	200	Bit.	West.	West.	Vert.	95	190
Corpus Christi.	Peoples' Light Co.		1908	S.	125	125	Lig.	Smith.	Rathbun.	Vert.	125	125
Dallas.	Iola Portland Cement Co.		1907	D. d.	3,000	3,000	Lig.	L. P.	Snow.	Horiz. tan.	1,100	4,400
Do.	Southwestern States Portland Cement Co.		1909		1,250	3,750	Lig.	Harvey.	A. C.	Horiz.	1,000	2,000
Gainesville.	Gainesville Electric Co.	Electric light.	1909	S.	150	150	Lig.	Smith.	Nash.	Vert.	150	150
Garwood.	G. H. Reinking & W. S. Hunn.		1909		200	200	Lig.	F. M.	F. M.	Vert.	200	200
Gatesville.	Gatesville Electric Light Co.	Electric light.	1909	S.	75	75	Lig.	Smith.	Muenzel.	Horiz.	75	75
Huntsville.	Huntsville Electric Light & Ice Co.		1910		100	100	Lig.	F. M.	F. M.	Vert.	100	100
Kingsville.	Kingsville Light & Ice Co.	Electric light.	1909	S.	100	100	Anth.	Smith.	Rathbun.	Vert.	100	100
Leonard.	Leonard Electric Light Co.	Electric light.	1908	S.	65	65	Lig.	F. M.	F. M.	Horiz.	50	50
Mart.	Home Light & Power Co.	Electric light.	1908	S.	100	100	Lig.	F. M.	F. M.	Vert.	100	100
Mineola.	Mineola Light & Ice Co.	Electric light.	1908	S.	100	100	Lig.	Smith.	Rathbun.	Vert.	100	100
Pittsburg.	Pittsburg Electric & Ice Co.		1910		100	100	Lig.	West.	West.	Vert.	75	75
Rockport.	Rockport Light & Ice Co.	Electric light.	1908	S.	65	65	Lig.	F. M.	F. M.	Vert.	50	50
Royse City.	Royse Milling & Light Co.	Flour mill and city light.	1905	S.	75	75	Anth.	F. M.	F. M.	Vert.	70	70
San Angelo.	San Angelo Power & Traction Co.	Electric railroad.	1908	S.	250	250	Anth.	Smith.	Alberger.	Horiz.	250	250
San Antonio.	San Antonio Portland Cement Co.	Electric transmission.	1909	S.	200	600	Anth.	Smith.	A. C.	Horiz.	600	600
Do.	do.	Electric transmission.	1911	S.	200	600	Anth.	Smith.	Rathbun.	Vert.	500	500
Smithville.	Smithville Electric Light & Water Co.		1907	S.	150	150	Lig.	F. M.	F. M.	Vert.	150	150
Stephenville.	Stephenville Light & Water Co.	Electric light and cotton gin.	1908	S.	100	100	Lig.	F. M.	F. M.	Vert.	100	100
Taylor.	T. W. Marse & Co.	Coffee roasting	1906	S.	20	20	Anth.	F. M.	R. M.	Horiz.	20	20
Teague.	J. G. Gugolz.	Power and light.	1908	S.	50	50	Lig.	F. M.	F. M.	Horiz.	50	50
Yorktown.	Yorktown Light & Ice Co.	Electric light.	1907	S.	60	60	Lig.	Smith.	Rathbun.	Vert.	60	60

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Utah:												
Modena	Gold Springs Mining & Power Co.		1910	S.	175	350	Lig. or bit.	West	West	Vert	160	320
Ogden	Knudson & Doon	Flour mill	1906	S.	75	75	Anth	F. M	F. M	Vert	43	43
Salt Lake	City of Salt Lake		1906	S.	200	200	Anth	F. M	F. M	Vert	150	150
Vermont:												
Bradford	Pike Hill mines		1906	S.	80	80	Anth	Otto				
Underhill	J. E Foster	Feed mill	1907	S.	50	50	Anth	Smith	Pohl	Horiz	50	50
Virginia:												
Bedford City	Bedford Coal & Mill Co.	Flour mill	1905	S.	50	50	Anth	F. M	F. M	Horiz	45	45
Columbia	T. R. Willard	Mill	1907	S.	35	35	Anth	Smith	Columbus	Horiz	35	35
Draper	Rex Milling Co			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Keyesville	Keyesville Milling Co			S.	50	50	Anth	Backus				
Lynchburg	United Cigarette Machine Co.		1906	S.	45	45	Anth	Otto				
Do	do		1908	S.	100	100	Anth	Smith	Foos	Vert	100	100
New Market	J. D. Manor & Co	Flour mill	1911	S.	75	75	Anth	Smith	B. M	Vert	75	75
Oak Ridge	Thomas F. Ryan	Electric light	1909	S.	50	50	Anth	Smith	Nash	Vert	50	50
Do	do	Private waterworks.	1909	S.	28	28	Anth	Smith	Nash	Vert	28	28
Do	do	Electric transmission.	1910	S.	100	100	Anth	Smith	Nash	Vert	100	100
Richmond	American Locomotive Co.	D.C. generator	1907	P.	500	500	Bit	Wood	West	Horiz	500	500
Do	W. H. Dunn			S.	20	20	Anth	Weber	Weber	1-cyl. horiz	20	20
Do	Mayo Milling Co			S.	125	125	Anth	Weber	Weber	2-cyl. vert	125	125
Staunton	Andrew Bolling		1906	S.	27	27	Anth	Otto				
West Point	People's Light, Heat & Power Corporation.		1912	S.	80	80	Anth	Smith	B. M	Vert	80	80
Woodstock	W. S. French			S.	20	20	Anth	Weber	Weber	1-cyl. horiz	20	20
Washington:												
Kings Siding	M. J. Lee (D. H. King)			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Olympia	Olympia Brewing Co	Refrigerating machine.	1907	S.	250	250	Lig	M. S. & M	Muenzel	Horiz. sing. act.	250	250
Seattle	State Irrigation Co			S.	250	250	Anth	Weber	Weber	3-cyl. vert	250	250
Do	University of Washington.		1912	S.	50	50	Anth	Otto				
Sedro Woolley	Ira M. Krutz	Refrigerating plant.	1912	S.			Lig	M. S. & M	Muenzel	Horiz. sing. act.	55	55
Spokane	Pine Creek Dairy Co	Irrigation		S.	25	25	Lig	Smith	Capitol	Horiz	25	25
Do	Western Development Co.	Irrigation		S.	25	25	Lig	Smith	Capitol	Horiz	25	25

White Bluffs	White Bluffs Irrigation Co.		1908	S.	150	150	Lig	Smith	Riverside	Horiz	150	150
Do	White Bluffs Land & Irrigation Co.		1907	S.	100	100	Lig	Smith	Rathbun	Vert	100	100
Wisconsin:												
Beloit	Fairbanks-Morse Manufacturing Co.	Factory power	1905–6	S.	6×150 +200	1,100	Anth	F. M	F. M	6 vert 1 horiz	150 200	1,100
Do	do		1909	S.	200	200	Anth	F. M	F. M	Vert	200	200
Do	do		1910		500	500	Anth	F. M	F. M	Horiz	500	500
Do	Wright D. Sturtevant Co.		1909		75	75	Anth	F. M	F. M	Horiz	50	50
Bondurel	R. M. Bondurel Co.		1910	S.	75	75	Anth	F. M	F. M	Vert	75	75
Brillion	Poustian Manufacturing Co.			S.	100	100	Anth	Weber	Weber	3-cyl. vert	100	100
Campbellsport	Campbellsport Electric Light & Power Co.	Electric light	1910	S.	100	100	Anth	Smith	Nash	Vert	100	100
Cudahy	Power & Mining Machinery Co.		1904	D. d.		2,000	Bit	L. P	American Crossley.			
Do	do		1908	D. d.	1,000	1,000	Bit	P. & M	Ingeco	Vert	150	300
Do	do		1912	S.	150	150	Anth	P. & M	Ingeco	Vert	200	200
De Pere	City of De Pere Waterworks.	Waterworks	1905	S.	45	45	Anth	Otto				
Fairchild	Foster Lumber Co	Belted power	1906	S.	60	60	Anth	Smith	Rathbun	Vert		
Janesville	Lewis Milling Co			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Juneau	Brodessor Motor Truck Co.	Belted power	1906	S.	85	85	Anth	Smith	Rathbun	Vert	85	85
Lancaster	Lancaster Electric Co	Electric light	1912	S.	200+300	500	Anth	Smith	Turner-Fricke	Vert	150+220	370
Madison	Democrat Printing Co		1910				Anth	F. M	F. M	Horiz	25+35	60
Do	Madison-Kipp Lubricator Co.	Electric transmission.	1910	S.	75	75	Anth	Smith	I. H. C	Vert	35	35
Do	Steinle-Turret Machine Co.			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Do	University of Wisconsin	Experimental	1905	S.	25	25	Anth	Wile				
Do	do	Experimental	1906	S.	20	20	Anth	F. M	F. M	Horiz	20	20
Manitowoc	Keune & Keune			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Do	Northern Wisconsin Produce Co.		1910	S.	50	50	Anth	Smith	Nash	Vert	50	50
Do	Wisconsin Knitting Co			S.	15	15	Anth	Weber	Weber	1-cyl. horiz	15	15
Do	do	Power	1909	S.	60	60	Anth	Smith	Rathbun	Vert	60	60
Merrill	Lincoln Mill & Elevator Co.	Flour mill	1908	S.	75	75	Anth	F. M	F. M	Vert	65	65
Milwaukee	Wm. A. Alder Co		1910	S.	75	75	Anth	F. M	F. M	Horiz	50	50
Do	Chain Belt Co	Power for foundry.	1906	S.	60	60	Anth	Smith	Rathbun	Vert	60	60
Do	Harley Davidson Motor Co.	Electric transmission.	1909	S.	100	100	Anth	Smith	Nash	Vert	75	75
Do	C. E. Dingwell		1909	S.	50	50	Anth	F. M	F. M	Horiz	50	50
Do	Luick Ice Cream Co		1909	S.	125	125	Anth	Luick-Bassett.	B. M	Vert	115	115
Do	Milwaukee Motor Co		1907	S.	100	100	Anth	Smith	Rathbun	Vert	100	100
Do	Milwaukee Stove & Foundry Co.		1910	S.	200	200	Anth	F. M	F. M	Horiz	160	160
Do	R. J. Schwab & Sons Co.	Electric transmission.	1906	S.	100	100	Anth	Smith	Rathbun	Vert	115	115

Producer-gas power installations in the United States—Continued.

Location.	Firm.	Service.	Date of installation.	Type of producer.	Horsepower (each unit).	Total producer horsepower.	Fuel.	Make of producer.	Make of engines.	Type of engines.	Horsepower (each engine).	Total engine horsepower
Wisconsin—Contd.												
Milwaukee	A. O. Smith Co		1909	P.		700	Anth	Wood	A. C			
Do	do	Electric transmission.	1911	S.	300	300	Anth	Smith	A. C	Horiz		
Do	Universal Machine Co	Power	1910	S.	50	50	Anth	Smith	Nash	Vert	50	50
Medford	City of Medford		1910		50	50	Anth	F. M	F. M	Vert	50	50
New Holstein	C. F. Dumke	Flour mill	1909	S.	75	75	Anth	Smith	Foos	Vert	75	75
Do	John Lauson Manufacturing Co.	Power	1909	S.	50	50	Anth	Smith	Lauson	Horiz	50	50
Osceola	Osceola Mill & Elevator Co.	Mill and light.	1907	S.	55	55	Anth	M. S. & M	Muenzel	Horiz. sing. act.	65	65
Oshkosh	Oshkosh Excelsior Manufacturing Co.			S.	150	150	Anth	Weber	Weber	2-cyl. vert	150	150
Plainfield	Starks & Skul		1910		100	100	Anth	F. M	F. M	Vert	100	100
Port Washington.	Gilson Manufacturing Co.		1910		160	160	Anth	F. M	F. M	Horiz	160	160
Do	Milwaukee Northern Ry. Co.		1907	D. d.		4,000	Bit	L. P	A. C	Twin tan. dble. act.	1,500	4,500
Racine	Harvey Springs Co	Belted power	1906	S.	60	60	Anth	Smith	Rathbun	Vert	60	60
Do	do	Belted power	1908	S.	60	60	Anth	Smith	Rathbun	Vert	60	60
Do	Hilkers-Weichers Manufacturing Co.			S.	60	60	Anth	Weber	Weber	2-cyl. vert	60	60
Do	do	Electric transmission.	1910	S.	150	150	Anth	Smith	Wiscon	Horiz	150	150
Do	McCrum & Howell Co	Electric transmission.	1909	S.	75	75	Anth	Smith	Nash	Vert	75	75
Do	Mitchell-Lewis Motor Co.	Electric transmission.	1907	S.	85	85	Anth	Smith	Rathbun	Vert	85	85
Do	do	Electric transmission.	1908	S.	125	125	Anth	Smith	Rathbun	Vert	125	125
Do	do	Electric transmission.	1909	S.	250	500	Anth	Smith	Rathbun	Vert	500	500
Do	Dr. Shoop Family Medicine Co.	Electric light and power.	1907	S.	60	60	Anth	Smith	Rathbun	Vert	60	60
Reedsville	City of Reedsville	Waterworks	1907	S.	50	50	Anth	Smith	Columbus	Horiz	50	50
Sheboygan	Hand Knit Hosiery Co	Power	1911	S.	50	50	Anth	Smith	Nash	Vert	50	50
Viroqua	Viroqua Electric Co	Electric light	1908	S.	150	150	Anth	Smith	Rathbun	Vert	150	15
Waupun	State of Wisconsin	Electric transmission.	1908	S.	200	400	Anth	Smith	Rathbun	Vert	400	40
West Bend	City of West Bend	Waterworks	1907	S.	50	50	Anth	Smith	Columbus	Horiz	50	50
Wyoming:												
Depass	Depass Mercantile Co		1908	S.	65	65	Lig	F. M	F. M	Vert	65	66
Wheatland	Town of Wheatland		1910		100	100	Bit	West	West	Vert	85	85

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